

DESIGN AND LAYOUT ANALYSIS FOR THE CONTROL
OF HAZARDS IN INDUSTRIAL PLANTS

A THESIS

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by

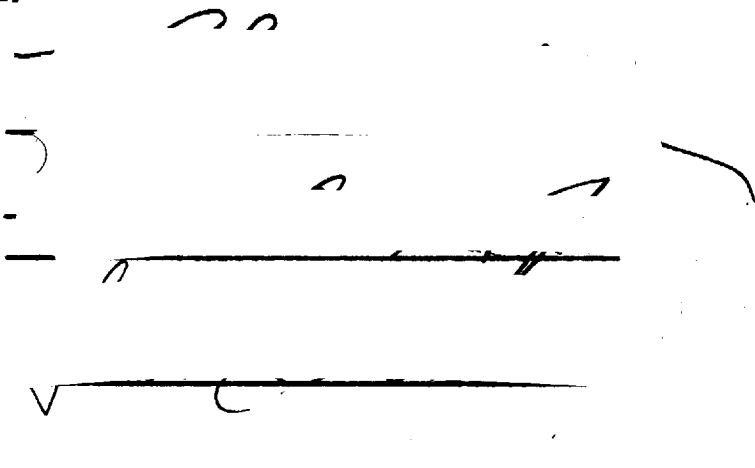
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June 1948

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Approved:

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Date Approved by Chairman 31 May 1948

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I

INTRODUCTION

With the impetus furnished by certain progressive industrial firms and a growing appreciation of management responsibility for accident prevention the practice of Industrial Safety has altered from the predominantly corrective type of activity to the preventive type. By corrective activity is meant the remedy of unsafe conditions after they have been revealed by accidents, and primarily by those resulting in serious injuries or catastrophes. Preventive Safety consists of the elimination of unsafe conditions revealed by an analysis of hazards supplemented by a study of accident records. In an advisory and research capacity, the insurance companies and safety organizations have contributed to the attack on the problem. Their work has been carried out through specific advisory services as well as through the publication of a large number of bulletins, codes, and standards on equipment, work methods, processes, protective devices, building construction, materials - in fact, on every conceivable phase of industrial activity and physical situation.

But in spite of the effort being spent on the analysis and control of hazards, approximately 540,000 industrial workers received disabling injuries during 1947. Including all occupations of workers the fatalities resulting from on-the-job accidents numbered 17,000 - an increase of 500 over the previous year.¹ The loss in wages to those affected is conservatively estimated at \$80,000,000. Statistical experience indicates that, including those which did not produce injuries, the total number of accidents was around 150,000,000!²

ACCIDENT CAUSES

Accident causes have been classified in considerable detail for purposes of accident prevention research.³ Reference to the two prime causes will, however, be sufficient to establish an important fact at this point. A number of studies have been made to determine the relative significance of the two prime causes, Unsafe Mechanical or Physical Conditions and Unsafe Acts of Persons. There are some variations in the conclusions due to the data used and differences in personal judgement in ascribing the major cause but the general pattern of the conclusions is consistent. The study conducted by the National Safety

¹Bureau of Labor Statistics, U. S. Department of Labor, Washington, D. C. Special Mimeographed Bulletin.

²H. W. Heinrich, Industrial Accident Prevention, New York McGraw-Hill, 1941. pp 26-27

³Proposed American Recommended Practice for Compiling Industrial Accident Causes - Z16.2, American Standards Association, New York.

Council produced these findings:⁴

1. 18% are due wholly to mechanical causes
2. 19% are due wholly to personal causes
3. 65% are due wholly to a combination of both causes
4. 81% are due wholly or in part to mechanical causes
5. 82% are due wholly or in part to personal causes.

A study sponsored by the Pennsylvania Department of Labor and Industry attributed only 2% of accidents wholly to unsafe acts of persons.⁵

Accepting the lower figure, however, it becomes evident that in at least 80% of reported industrial accidents unsafe mechanical or physical conditions have been a substantial or sole factor. Though accidents occur in a brief period of time, the hazards which produce them are a constant nuisance, often lowering the productive efficiency of a plant, until they are brought under control.

INDUSTRIAL HEALTH HAZARDS

Not all hazards are of the type which produce accidents. Many have existed in industries for years without detection, taking a steady toll in restricted production through illness, occupational diseases, and excessive fatigue. In the majority of cases the results are produced by repeated exposure of persons to the hazard over a period of time and are manifested slowly. Because the effects generally appear slowly, health hazards are more easily over-looked than those which

⁴R. P. Blake, editor, Industrial Safety, New York: Prentice-Hall, Inc., 1946. p.46

⁵Loc. cit.

produce traumatic injuries through accidents.⁶ Because of the longer convalescent and re-habilitation periods usually involved an occupational disease case is probably even more costly to industry than an accident.

THE COST OF HAZARDS

The cost of accidents is only a part of the total cost of hazards. Yet that part in itself is so considerable and so frequently under-estimated by executives that it is worthwhile to quote an analysis of accident cost elements by an outstanding authority on industrial accident prevention.⁷

1. Cost of lost time of injured employee.
2. Cost of time lost by other employees who stop work:
 - a. Out of curiosity
 - b. Out of sympathy
 - c. To assist injured employee
 - d. For other reasons
3. Cost of time lost by foremen, supervisors, or other executives:
 - a. Assisting injured employee
 - b. Investigating the cause of the accident
 - c. Arranging for the injured employee's duties to be carried on by another employee
 - d. Selecting, training, or breaking in a replacement
 - e. Preparing state accident reports, or attending hearings before state accident officials.
4. Cost of time spent on the case by first-aid attendant and hospital department staff.
5. Cost due to damage to the machine, tools, or other property, or to the spoilage of material.

⁶H. W. Heinrich, op. cit. pp.289-291

⁷Ibid., pp.26-27

6. Incidental cost due to interference with production, failure to fill orders on time, loss of bonuses, payment of forfeits, and other similar causes.
7. Cost to employer under employee welfare and benefit systems.
8. Cost to employer in continuing the wages of the injured employee in full, after his return - even though the services of the employee (who is not yet fully recovered) may for a time be worth only about half their normal value.
9. Cost due to the loss of profit on the injured employee's productivity, and on idle machines.
10. Cost of subsequent injuries that occur in consequence of the excitement or weakened morale due to the original accident.
11. Overhead cost per injured employee - the expense of light, heat, rent, and other such items, which continue while the injured employee is a non-producer."

These are some elements of the cost of an accident. But if that accident were due, say, to inadequate lighting, the hazard itself may have cost the employer a considerable amount day in and day out, year after year, before an accident ever occurred. When the level of illumination in an electric locomotive repair shop was increased from 5 foot-candles to 20 foot-candles it was discovered that production increased 10% and rejects by the inspection department went down 80% as compared to the previous six-month period.⁸ The owner of an unsprinklered warehouse usually pays substantially, through higher insurance premiums, for the privilege of maintaining his hazard. On the evidence of case studies such specific benefits as the following may be anticipated as a result

⁸"What Better Lighting Did for One Shop," National Safety News, 53:78, March, 1946.

of the reduction of hazards:

1. Increased production
2. Decreased spoilage
3. Lower turnover of personnel
4. Decreased rapair costs
5. Decreased accident costs
6. Other benefits which are difficult to evaluate quantitatively
 - a. Improved labor relations
 - b. Improved public relations
 - c. Improved position in the labor market.

Most of these benefits, it may be noted, relate to major executive responsibilities; and so it is not surprising that in progressive organizations Industrial Safety receives top-management attention.

In the face of generally rising costs, the B. F. Goodrich Company of Akron, Ohio, recently doubled its safety program.⁹ The company had by no means been lax in previous efforts. Its executives acted, rather, out of the conviction that an investment in Safety pays dividends. This illustration serves to introduce and emphasize the important point that management must be willing to authorize the expenditures necessary to realize the savings and other benefits of reduced hazards.

THE PREVENTION OF HAZARDS

It is a fundamental premise of this investigation, and one scarcely necessary of proof, that it is more economical to avoid the

⁹T. J. Cain, Jr., "How We Convince 22,000 Workers That Safety Is Their Business," Factory Management & Maintenance, 105:114, December, 1947.

inception of hazards than it is to remove them, once in existence. And the logical point for the identification and elimination of incipient hazards is the design and layout stage of the industrial plant - whether it be the re-arrangement of one department, the complete modernization of a plant, or the planning of an entirely new unit. A prominent Plant Layout Engineer agrees that "In planning a plant, potential hazards can be engineered "into" or "out of" the layout." ¹⁰

The elimination of hazards at the point of inception is a problem in engineering analysis, the solution of which is justified on economic as well as humanitarian bases. No attempt will be made to show that the Plant Layout Engineer should supplant a specially trained Safety Engineer; rather, subsequent chapters will reveal the necessity for closer cooperation between these two staff authorities and a greater appreciation of the safety specialist. On the other hand, many small plants do not have such a staff specialist and in larger plants the Layout Engineers are not always fully aware of the assistance that can be given them, nor do they always know when to ask for it. Though an inadequate appreciation of the problem's importance is partially responsible, the situation is due in a large measure to the quantities of code, bulletin, and recommended practice material which are not organized to be readily useful to other than one who is a specialist in Industrial Safety. The purpose of the writer, therefore, has been to

¹⁰R. W. Mallick, "Are You Planning Accidents?" National Safety News, 53:22, June 1946.

provide an integrated approach to the problem from the viewpoint of the Layout Engineer.

II

THE IMPORTANCE OF SPACE

No idea is more fundamental to the art of Plant Layout than the concept of space. That concept by itself, however, is inadequate. Frank Lloyd Wright, the peer of modern architects, in explaining his functional approach to design described the home as "space for living." Similarly, the industrial plant is space for working. The dynamic concept of space lies behind every successful plant design.

BASIC DEFINITIONS

Unfortunately, a parting of the ways occurs when those who do not understand the concept of space and its functions attempt to evaluate a plant layout. They are wont to measure it with a yardstick called "space utilization" by which they mean, in effect, the hours of occupancy (by men, materials, or equipment) per cubic foot. It is difficult for them to comprehend that functional space utilization may necessitate a low occupancy in many cases, or that such a low occupancy is not 'a priori' proof of inefficiency.

The idea of functional space utilization can be clarified by a simple example. Eliminating one dimension we may, for a moment, consider the land - or area - utilization of an airport. A very small percentage of the total area is 100% occupied by hangars, repair shops, passenger terminal, and other facilities. The aprons used for loading, un-loading, and temporary storage of aircraft sustain less than a 50% hour-occupancy

load and the runways even less. The approaches, totalling as much as a hundred or more acres, are never occupied by either buildings or equipment; yet they are functionally indispensable, for aircraft could not safely take-off or land without them.¹¹ It is obvious that while the overall occupancy of the land by buildings, equipment, and personnel is extremely low a near perfect functional utilization of space may be achieved.

The foregoing development of the simple idea of space leads to the definition of Plant Layout as planning for the maximum functional use of space. This definition, or interpretation, underlies the approach to the problem of hazard reduction in the following chapters. To secure consistency the term "space utilization" will be used also in the functional sense, and "degree of occupancy" will be used to indicate the relative quantity of men, machines, or material physically present.

One more term must be defined to clarify the analysis. It follows logically from the functional concept of Plant Layout and constitutes the base of departure for nearly all that follows. The loose usage of the term "waste space" to signify empty space must be discarded and the term restricted to mean space which serves no function. The function of empty space in certain places has been indicated briefly and will be developed throughout the text. Quotation marks will always be used hereafter when there is intention to imply the unrestricted meaning.

¹¹Space fulfilling this type of function is known as "clearance," and is a vital factor in industrial safety.

FUNCTIONS OF SPACE

The illustrative example of an airport may have suggested that, for analytical purposes, space can be divided into various functional types and that the anticipated degree of occupancy will vary according to the function. All space within an industrial plant can be classified rather easily according to the following tabulation:

<u>Function</u>	<u>Degree of Occupancy</u>
1. Production	Moderately High
a. Fabrication	
b. Assembly	
c. Inspection	
2. Traffic & Transportation	Low to Moderate
3. Storage	High
4. Plant Service Facilities	Moderate to Moderately High
5. Employee Service Facilities . . .	Low to Moderate
6. Clearance	Zero

Such a classification provides a convenient and logical approach to layout design and to the analysis of hazards in layouts.

SPACE, CLEARANCE, AND HAZARDS

Many hazards may be resolved at least partly into a function of space - mainly in the form of clearance. A head injury due to low overhead clearance - a twisted ankle due to a projecting length of pipe in a warehouse aisle - thousands of dollars of water damage from a hundred-dollar fire because high-stacked merchandise cut off water distribution from sprinkler heads and allowed heat to build up and set

off other heads. These and many others are cases where space - empty space - would have reduced or eliminated the hazards. The writer observed the fire exit on the third floor of an Atlanta cotton mill completely blocked by four rows of tote boxes because inadequate space had been provided for storage. For all practical purposes the emergency exit could have been non-existent, yet neither management nor the workers seemed to recognize the hazard.

The lack of adequate space does not appear to be peculiar to any particular type of functional area. A prominent plant engineer writes:¹²

"....In any one of a number of plants that are today considered quite modern from the standpoint of equipment layout, the aisles are entirely inadequate for the traffic which they must bear. One of the reasons for this condition is that management often feels that aisles are wasted space; therefore, they should be kept as narrow as possible. Saving floor space in this manner can often prove to be a very wasteful and inefficient practice."

It seems strange indeed that the executives who are most concerned with efficiency would ignore any contributing factor. This parsimony of management regarding the provision of adequate space stems from the mis-conceived notion of space utilization which was discussed previously. The situation is not novel, for the development of Scientific Management has been marked by the discard of many attitudes, once strongly entrenched, which fell before logical analysis and practical demonstrations of their inaccuracies. Thus the realization of the economies and other benefits to be derived from the reduction of hazards is, among other things, contingent upon the recognition by executives and engineers of the functional importance of space.

¹²R. W. Mallick, "Minimize Accident Hazards with Modern Plant Layout," Industry and Power, 51:77, August, 1946.

III

PRODUCTION AREAS

Although numerous facilities and services are essential for operation or contribute to the efficiency of the industrial plant, the function to which all others are subordinate is production. The production areas are the heart of the plant - its sole reason for being. The production activities are the most varied, the most complex of all that occur within the plant. It is to be anticipated, therefore, that the greatest variety of hazards will be found in the production areas.

It would be difficult to formulate a logical organization on the basis of the many individual hazards which might be present in production areas. However, a development paralleling the step-by-step procedure in plant design provides an analytical approach amenable to the purposes of hazard control. This approach suggests that attention be directed successively to the following phases of planning for the productive functions of the plant:

1. Analysis of the product, and particularly, the materials used in its fabrication (effect of hazards on basic plant features.)
2. Consideration of the hazards introduced by the manufacturing processes, including special factors which affect the location thereof.
3. Special attention to safety in the selection of equipment.
4. Consideration of the hazards related mainly to the arrangement and installation of equipment and machinery.
5. Analysis of the layout to ascertain if adequate provision has been made for housekeeping.

Certain other factors, such as illumination, which are of fundamental significance in all parts of the plant will be considered separately in Chapters VI, "Plant Services," and VII, "General Working Conditions and Employee Facilities."

THE PRODUCT

At most, the plant design engineer can merely suggest changes in the product or substitutions in respect to the materials of which it is made. Usually he has little or no voice at all in setting product specifications. The properties of the product or material, however, may be of primary importance in terms of hazards. A plastics molding plant using cellulose nitrate as the basic material would be a substantially different design problem if cellulose acetate were the basic material. The first instance would present a fire and explosion hazard that could not intelligently be ignored. In general, hazards indigenous to the material are plant-wide unless they are:

1. Confined by functional plant design and layout, or
2. Confined by the process and equipment, or
3. Eliminated by a change in the material at some stage in the production process.

Hazards inherent in the material nearly always fall into one of three classes and a few materials may be catalogued in several classes.

1. Fire Hazards (combustible materials)
2. Explosion Hazards
 - a. Air mixtures of gases, vapors, or dust suspensions of substances ordinarily classified merely as combustible.
 - b. Materials which are explosive in all normal forms.

3. Industrial Health Hazards¹³

- a. Noxious fumes, vapors, and dusts which enter the body through the respiratory system
- b. Corrosive substances (contact hazards)
- c. Substances which produce allergic reactions in some people

Particular effort should be made to identify those situations where a by-product of the material or the material itself in certain forms or under certain conditions may present a severe hazard even though it is not considered dangerous in its normal situation. Because these hazards can be so easily overlooked they have contributed to many of our major industrial disasters.¹⁴

Fire Hazards. Where it is necessary to "live with" a substantial fire hazard it seems only sensible to provide for confining and controlling fires which might kindle and for limiting damage as much as possible. The best protective features which may be incorporated in a plant are a

¹³A. D. Brandt, Industrial Health Engineering, New York; John Wiley & Sons, 1947. Chapter I, pp. 1-32.

¹⁴A tragic case in point was the Texas City, Texas, Disaster. Over five hundred lives were lost and over thirty million dollars of property damage was sustained as a result of the explosion of a substance (Ammonium Nitrate Fertilizer) which is not even particularly flammable at atmospheric temperatures. Chemically, it is considered an "incombustible salt." The United States Department of Agriculture does not consider Ammonium Nitrate as explosive when stored (as it was) in paper bags segregated from other materials classified as explosives. The labels on the bags carried no warnings and none of those who were handling the material or fighting the fire which preceded the blast was aware of the explosion hazard under certain conditions of moisture and impurity content, density, packing, crystalline form, etc.. Yet a similar disaster in 1923 at Oppau, Germany, cost four hundred and fifty lives and destroyed over seven hundred homes. Texas City, Texas, Disaster, Special Report of The Fire Prevention and Engineering Bureau of Texas and The National Board of Fire Underwriters, New York: 1947.

matter of basic design and, thus, should be anticipated early in the planning stage. Building height should be limited in order to facilitate control of fires, protect personnel, and limit damage. Fire-resistant construction is necessary, and all large areas should be divided by fire-walls extended above the roof level. Obviously, the value of fire-walls would be largely lost unless the necessary openings in them and in floors are properly protected by an effective closure.¹⁵ It is sometimes advisable to locate the plant in several inter-connected buildings rather than in one large structure. Roof vents for the dispersal of smoke and fumes and the release of pressures built up during combustion are desirable. A sprinkler system should be specified and the installation so planned as to protect the system from freezing. Floors above the first should be water-proofed and designed for effective drainage in order to prevent water damage on lower floors.¹⁶

Where highly flammable materials are employed in substantial quantities, so that a fire could spread with great rapidity, a flash-fire hazard is said to exist. Ordinary safeguards are ineffective in a situation of this sort. The common type of sprinkler system reacts too slowly and applies too little water to cool the material below the kindling point. Instead, a "deluge" system actuated by a rate of temp-

¹⁵Regulations for the Protection of Openings in Walls and Partitions, (NBFU Pamphlet # 80) National Board of Fire Underwriters, New York: January, 1939.

¹⁶Suggestions for Waterproofing of Floors and Drainage, and Installation of Scuppers, (NBFU Pamphlet # 92) National Board of Fire Underwriters, New York: November, 1937.

erature rise¹⁷ control must be provided in order to secure any real measure of protection. The same control may be used to actuate water curtain protection for openings in fire-walls. Systems of this type have proven effective in controlling and extinguishing fires in refineries and aircraft hangars - usually among the most difficult to subdue. An additional result of flash-fires which must be reckoned is the extremely rapid expansion of the gaseous products of combustion. An adequate venting system is indispensable.

Detailed recommendations for the reduction of ordinary fire hazards are included in the National Building Code of the National Board of Fire Underwriters, while standards for the control of flash-fire hazards have been promulgated in terms of specific types and are available separately in pamphlet form.¹⁸ The basic approach to the problem, however, is the same in all cases:

¹⁷The usual type of sprinkler system is actuated by an absolute temperature device, usually of the fusible link type. To prevent accidental release the temperature at which the device operates is set higher than would be desirable from the standpoint of maximum sensitivity and minimum lag. The lowest temperature in use for this type of system is about 125°F.. The rate-of-rise actuating device, however, is independent of absolute temperature within practical ranges and maintains a high degree of sensitivity with an extremely short lag.

¹⁸Specific standards for the storage, handling, and use of a number of hazardous materials are published and circulated in pamphlet form by the National Board of Fire Underwriters, 85 John Street, New York 7, N. Y., These are useful not only in regard to the specific situations for which they were drawn but also for their suggestive value in respect to similar materials for which specific standards are not available. Among those in current circulation are:

NBFU Pamphlet #	32	Dry Cleaning and Dry Dyeing Plants
"	"	42 Pyroxylin Plastic
"	"	44 Combustible Fibres

1. Reduce the probability of the event occurring
2. Provide means for limiting the effects of the event

This is the practical alternative to the physically or economically impossible ideal of absolutely preventing its occurrence.

Industrial Explosion Hazards.¹⁹ Nothing can be added here to the literature on the highly specialized problem of designing plants for the production of explosives, per se. The control of hazards has been a primary functional objective and has received the attention of experienced specialists. To a great extent this is also true of oil refinery design. However, many of the plant features which have been developed in these industries may be adapted to other industrial plants where explosion hazards exist. Among the methods for reducing explosion hazards are the following:

1. Location of the plant in a number of buildings separated so as to minimize exposure to fire and blast damage
2. Limitation of individual building height and size
3. Provision for release of pressure
4. Installation of exhaust system to reduce concentrations of dusts, gases and vapors.²⁰

¹⁹The pamphlets of the National Board of Fire Underwriters, New York, and the National Safety Council, Chicago, provide considerable detailed information and recommendations relative to industrial explosion hazards and their control.

²⁰Blower and Exhaust Systems for Dust, Stock and Vapor Removal or Conveying, (NBFU Pamphlet # 91) National Board of Fire Underwriters, New York: February, 1947.

Industrial Health Hazards. Materials which are considered industrial health hazards produce their harmful effects through some form of interior or exterior body contact. Most solutions to the various phases of the problem have been in terms of process control, equipment, and protective devices and not through basic plant features. The only significant exception is ventilation. The control methods, therefore, can be discussed more conveniently at a subsequent point in the chapter in relation to processes and equipment.

PRODUCTION PROCESSES

In the previous section the effects of hazards attributable to physical properties of the product and the material have been discussed in relation to basic plant design features. By comparison, the hazards inherent in processes are less extensive in their effects, as a rule, and less difficult to control. The ideal solution is the substitution of a non-hazardous process, or the complete elimination of the process through re-design of the product. Sometimes this is economically advantageous; more often it is not. Brandt makes the excellent point, supported by experience with atomic-bomb and military explosive plants, that any hazard can be controlled through proper engineering, and thus the choice of substitution or control is basically an economic one.²¹ Nevertheless, a logical approach to the problem must give consideration to every alternative; and, in general terms, the following would appear to be a

²¹A. D. Brandt, op. cit., p.51

complete list of possibilities:

1. Eliminate the process
2. Substitute a less hazardous or non-hazardous process
3. Isolate the process
4. Reduce the hazard
5. Protect personnel and property against the hazard

Only the first is automatically exclusive of the others, and most recommended methods of hazard control will involve a combination of several basic principles. A number of practical illustrations will serve to emphasize the manner in which the several basic methods contribute to the control of hazards.

Elimination of the Process. The elimination of a process can rarely be accomplished without a re-design of the product; and that action, in turn, is rarely initiated without the prospects of other benefits unless those resulting from the reduction of hazards are proved to be substantial. For example, the thermit welding of stern-post casting assemblies for ships could be eliminated by casting the entire stern-post in one piece. The process is not likely to be eliminated, however, as long as it is cheaper to cast and ship the stern-post in sections to the point of erection.

Substitution. Substitution of a less-hazardous process will be more feasible than elimination in the majority of cases. This method is well illustrated in the substitution of steel shot-blasting for sand-blasting with a resultant reduction of atmospheric dust concentra-

tion (an industrial health hazard) of as much as 80% in the blast room.²² The use of a closed steel-ball tumbling mill would still further reduce contamination of the air inhaled by personnel. On the other hand, a situation where substitution is not generally deemed feasible is to be found in the dry cleaning industry where the flammable solvent processes predominate because of quality and over-all cost factors.²³

Isolation. Isolation in some form or degree is recommended as a control measure for a large variety of industrial hazards from paint spraying²⁴ to X-Rays.²⁵ A quotation from the National Board of Fire Underwriters standards for paint spray booths is typical of their requirements for the control of similar hazards common to other processes (such as flow-coating, hardening & tempering, baking of japan finishes, etc.)

"2. Where possible, spraying processes should be located in a detached building or in a one-story properly cut-off addition. Severe spraying hazards, combustible occupancies and vulnerable construction or a combination of these conditions may require a standard fire cut-off, if the hazard is located in a large area exposing large combustible values.

Less severe conditions may call for enclosing partitions having a fire resistance of one hour or less, depending upon other conditions and the protection available.

Care should be taken not to make the enclosed spraying rooms so small as to increase the liability to explosive mixtures of vapors and air."²⁶

²²Ibid., p. 52

²³Dry Cleaning and Dry Dyeing Plants, (NBFU Pamphlet # 32) National Board of Fire Underwriters, New York. February, 1944.

²⁴A. D. Brandt, op. cit. pp.226-234

²⁵Ibid., pp.296-297

These recommendations are paralleled by those of the National Safety Council for spray coating processes:²⁷

1. Buildings separated from other manufacturing work.
2. One story cut-off additions.
3. Booths or rooms built beyond the walls of the regular building.
4. Specially constructed booths or enclosures inside regular buildings.

The purpose of isolation is, of course, to restrict any given hazard to the smallest possible area within a plant, thus minimizing the damage, injuries, and interference with other production which would result from an accident. A number of methods may then be utilized to reduce the hazard and provide protection, so that in a properly engineered process installation the residual hazard would be slight.²⁸

Reduction. Reduction is one of the most useful methods of controlling hazards, simply because it is so often economically or physically impossible to eliminate them. In the case of fire hazards reduction means decreasing the probability of ignition. In the case of industrial health hazards it means lowering the concentration of the contaminant or the exposure of personnel to it. A great many of the

²⁶Paint Spraying and Paint Booths, (NBFU Pamphlet # 33) National Board of Fire Underwriters, New York: October, 1946.

²⁷Spray Coating, (Safe Practices Pamphlet #91), National Safety Council, Chicago.

²⁸Though beyond the scope of this study, a true picture would not be conveyed without the remark that no amount of engineering can obviate the necessity for efficient maintenance, good housekeeping, and employee training in accident prevention.

most serious fire and health hazards are consequences of vapor or dust suspensions in air. The most effective known device for reducing hazards of this nature are local exhaust and blower systems.

An essential factor in the successful application of exhaust systems is the direction of flow; heavier-than-air mixtures should be exhausted downwards. Another important point which is sometimes overlooked where flammable vapors and dusts are concerned is that, with the higher concentrations of the material which are to be found within the duct system, explosive mixtures are likely to occur within the system itself. The ducts, therefore, should lead as directly as possible to the outside of the building and the system should be installed strictly in accordance with the Standards of the National Board of Fire Underwriters to minimize the possibility of ignition.²⁹ Of the information on local exhaust systems examined by this writer the most complete work on basic principles, detailed design data, hood types, etc., is that of A. D. Brandt,³⁰ Industrial Hygiene Engineer for the Bethlehem Steel Company. Though his work was done with reference to health hazards it may be applied equally *as* well to fire hazard problems (involving airborne materials) if installation of equipment is in accordance with the previously mentioned NBFU Standards.

The point has been made that either health or fire hazards due to

²⁹Blower and Exhaust Systems for Dust, Stock and Vapor Removal or Conveying, (NBFU Pamphlet #91), National Board of Fire Underwriters, New York: February, 1947.

³⁰A. D. Brandt, op. cit., pp.68-260.

air-borne materials may be reduced through lowering the concentration of the substance in the plant atmosphere by means of an exhaust system. The necessity of guarding against ignition within the exhaust system, where flammable mixtures are handled has also been noted. Sometimes it is advisable, in addition to the other precautions, to guard against ignition in the general vicinity of a process. The potential sources of ignition may be listed briefly as:

1. Open flames and hot surfaces
2. Static electricity
3. Sparks produced by striking contact of machinery parts and tools
4. Illuminating system (especially fixtures and switches)
5. Electric power system (especially motors and controllers)

Ignition sources of the first type must not be allowed in proximity to a severe hazard. Sources of the second type are neutralized by complete grounding of machinery and equipment; grounding wire to be not less than No. 8 gage copper and protected against mechanical injury.³¹ Ignition from the third source may be eliminated by the use of non-sparking materials (Ex. the use of beryllium copper hand tools in munitions plants.) Potential ignition from the latter two sources is minimized by installation of equipment in accordance with the National Electrical Code.³²

³¹Ovens for Japan, Enamel, and Other Flammable Finishes, (NBFU Pamphlet #86,) National Board of Fire Underwriters, New York, March, 1931.

³²National Electrical Code, (NBFU Pamphlet # 70,) National Board of Fire Underwriters, New York: Article 500.

In this section the reduction of hazards has been considered in two related but somewhat different senses. In respect to health hazards the term has been most literally applied to mean a reduction in the concentration of the hazard-creating substance. In respect to accident hazards (primarily fire) it implied a reduction in the probability of the event occurring, through various means in addition to decreasing the concentration of the hazard-producing substance.

Protection. Protection, like reduction, has a somewhat different connotation when applied to fire hazards than it does in reference to others. Through past usage the term refers to equipment that becomes active after a fire has kindled (i.e. protection against the consequences of the accidental event rather than against its occurrence.) Fire protection equipment is of three general types:

1. Alarm systems
 - a. Temperature-sensitive systems
 - b. Photo-electric detecting systems (flame or smoke)
 - c. Indirect systems (actuated by flow in sprinkler system)
 - d. Manual systems
2. Fire extinguishing systems
 - a. Automatic closed-head sprinkler systems
 - b. " open-head (deluge) sprinkler systems
 - c. " Chemical systems (CO_2 , CCl_4 , foam, etc.)
 - d. Standpipe and hose systems
 - e. Mobile cart units
 - f. Hand extinguishers
3. Salvage and rescue equipment

Where fire hazards are severe, competent authorities consider extensive protection, over and above other types of hazard control, as imperative. The following regulations of the National Board of Fire Underwriters are

indicative of their recommendations for protection against severe fire hazards.³³

"182. Extinguishing equipment shall be arranged to discharge one or more of the following extinguishing agents: water, carbon dioxide, or other inert gas, foam carbon tetrachloride, or steam as may be specified by the inspection department having jurisdiction. Water sprinklers may be required in addition to other protection for ovens or parts of ovens where combustible stock or drippings are present. Details of all proposed equipments shall be submitted to inspection department for approval before installation is made.

183. All extinguishing equipment shall be of approved type and shall preferably be automatic."

The desirable amount of fire protection should be determined for each plant according to the situation, with the necessary equipment and location thereof specified as an integral part of the plant design and layout.

Protection against hazards, other than fire, which may be inherent in a process is understood to designate the methods or devices which are provided to curtail accidents by reducing exposure to or contact with the hazards. Protection of personnel against exposure or contact is generally accomplished through two methods:

1. Individual items of protective clothing (such as safety shoes, electricians' gloves, etc.) or equipment (such as welders' shields.)
2. Protective features and safety devices incorporated in the process machinery.

The former lie without the scope of the present subject, the latter will be discussed in the following section.

³³Ovens for Japan, Enamel, and Other Flammable Finishes,
(NBFU Pamphlet #86,) National Board of Fire Underwriters, New York:
March, 1931.

EQUIPMENT SAFETY FEATURES AND DEVICES

Some of the greatest progress in the industrial-accident prevention movement has been made in the field of machinery and equipment. Perhaps this is due to the fact that the earliest efforts to promote industrial safety were in the field of machinery and equipment. English law first required the fencing of mill gears and shafts in 1844.³⁴ Massachusetts enacted a similar law in 1877. Heinrich refers to the establishment of the Safety Department of the Joliet Works of the Illinois Steel Company in 1892 as the beginning of the industrial-accident prevention movement.³⁵ The first safety order issued by that department was the inspection of all engine flywheels. The American Society of Mechanical Engineers (founded 1885) directed its first efforts in industrial safety to preparing recommendations for the guarding of power transmission machinery.

Nevertheless, by the time of World War I, few manufacturers had made any serious efforts to incorporate safety features and devices in their equipment - the burden of protection fell largely on the purchaser. Only within the last twenty years has acceptance of safety as an objective of functional machine design become fairly widespread. During the same period however, the mechanization of industry increased vastly and the machine hazard problem remains an important one. In New York State alone during 1940 there were attributed to machinery and equipment

³⁴H. W. Heinrich, op cit., p.367

³⁵Ibid., p.368

about 7600 compensated injuries, of which 50% resulted in permanent partial or total disability, or death.³⁶ Though none have been ideally successful, there is a variation in the degree to which manufacturers have provided for the safety of operating and maintenance personnel in the design of their products.

In the selection of equipment, therefore, safety should be a basic criterion. Where a machine under consideration is not adequately guarded or lacks other essential safety devices, the cost of correcting such defects should be included in an economy analysis for equipment selection purposes. Even when allowances are made, the probable inferiority of corrective measures as a substitute for sound basic design should be recognized.

A check list of general and specific features is often useful in evaluating items of machinery and equipment from the industrial safety viewpoint. As a class, unit-powered machines with enclosed drives present fewer hazards than line-shaft driven equipment in addition to their superiority in flexibility for layout and relative freedom from mass downtime. Other general factors are:

1. Gears and other mechanism contained within the body of the machine or substantially guarded, if not contained
2. Glass windows for necessary inspections of internal mechanism during operation
3. Power cut-off automatically operated when access doors or plates are removed for inspection and maintenance

³⁶R. P. Blake, op. cit., p. 179.

4. Single-point, sealed in, or easy access for lubrication to eliminate crawling over machine
5. Lack of projecting set-screws or other parts of moving elements which could snare clothing
6. Controls placed for convenient operation without leaning or reaching over moving parts
7. Emergency stop controls placed conveniently and in such number as required
8. Adequate clearances and/or guarding to prevent parts of the body or clothing being caught and drawn into machine
9. Lack of projecting sharp corners and edges on exposed parts.

Quite a number of guards and safety devices have been developed for specific types of hazards encountered with various machines.^{37,38,39,40,41}

The following is a partial list of those which have been tested in at least one application:

1. Sliding, chute, and rotating feeds
2. Automatic feeds
3. Automatic ejectors
4. Completely enclosed dies
5. Photo-electric devices
6. Interlocking devices

³⁷"Safeguarding Machinery," National Safety News, 51:131, March, 1945.

³⁸Power Presses, (General Safe Practices Pamphlet # 18), National Safety Council, Chicago.

³⁹Machine Shops, (General Safe Practices Pamphlet # 39), National Safety Council, Chicago.

⁴⁰H. W. Heinrich, op. cit., pp. 168-259

⁴¹R. P. Blake, op. cit., pp. 175-228

7. Two-handed tripping devices
8. Two-handed pull-out devices
9. Treadle guards
10. "Dead-man" controls
11. Gate guards
12. Sweep guards
13. Built-in equipment for handling heavy tools and jigs when the function of the machine requires relatively frequent changes.

While considerable attention has been devoted to the problem of providing for safe operation of certain types of machinery in the past, the problem of safe maintenance and set-up of the machine has too often been neglected.

LAYOUT OF PRODUCTION AREA

There is probably no area in an industrial plant which requires a more careful analysis of the functional space requirements and distribution than the production areas. The best production machinery obtainable may be rendered inefficient by improper layout. A competent layout engineer can visualize the situations which will arise when a plant is in full production, but it is often difficult for him to convince other management executives why he has "wasted" so much space around production equipment on his layout sketch or three-dimensional model layout. To fully explain the problem it is necessary to back-track a moment.

Before the actual layout can be started a considerable amount of preparatory work must have been done. It is necessary here, however, to

touch only on those factors which affect the problem at hand. The quantity of material to be handled into and out of the production area within a given period of time, the handling method and equipment, and the required aisle widths for expedient and safe handling must be determined. The quantity of work-in-process (i.e. the bank) at each machine and the space required must be calculated. Further, an allowance should be made for emergency storage in the production areas to avoid bottlenecks due to breakdowns, set-up and other delays. The space required for set-up, loading and unloading work from the machine should be known in addition to the space for actual operation (too often, there is adequate provision for the latter, only). Sufficient clearance for installation and maintenance is also necessary. In other words, the dynamic concept of plant layout implies considerably more planning than the mere placing of machines and men so as to obtain the maximum concentration in a given space. Production efficiency and the control of hazards due to congestion and inadequate clearances are both served through planning according to the functional utilization of space.

Some other factors which affect hazards are indicated in the following list together with a summary of space requirements:^{42,43}

1. Provide adequate space for handling materials
2. Provide adequate space for operating equipment
3. Provide adequate space for set-up, placing and removing work
4. Provide adequate space for machine bank (tote and skid boxes, and other types of temporary storage at machine)

⁴²"Design and Layout," National Safety News, 53:15, March, 1946.

⁴³R. P. Blake, op. cit., pp. 111-116.

5. Provide adequate space for emergency storage
6. Provide adequate space for installation, alteration, and maintenance
7. Provide for future expansion
8. Locate operating positions away from aisles
9. Locate work positions so that operator is not exposed to distracting influences
10. Do not exceed floor load limits.

The last point deserves additional emphasis because of its significance in changing layouts and re-modeling old plants. Permissible deadweight loadings frequently limit the location and spacing of certain machines. Floor construction and vibration limitations may exclude much of the modern high-speed equipment from proposed locations unless structural alterations are made to the building.

HOUSEKEEPING

Few factors in industrial safety have been more neglected in long-range planning than housekeeping. In many cases, no doubt, housekeeping has not even been considered as a design problem. Actually, however, there are a number of measures of great value which may be taken in designing and laying out production areas.^{44,45}

1. Provide a definite means for the removal of scrap and spoilage. Scrap and waste are an inevitable consequence of the production process.

⁴⁴E. F. Sharpe, "Scrap Handling System Paid For Itself In Two Months," Factory Management & Maintenance, 105:84-85, February, 1947.

⁴⁵Charles Knoblauch, "Eight Steps to a Clean Shop," Factory Management & Maintenance, 104:134-135, July, 1946.

2. Provide a definite place for every tool, jig, and item of equipment
3. Make it as difficult as possible for trash to accumulate unnoticed
4. Provide (especially where women are employed) small lockers or personal drawers in work benches.

Undoubtedly, this chapter would be expanded vastly if all the accumulated experience of plant design engineers could be recorded and organized. The purpose here has been primarily to indicate the major factors in the control of production area hazards, and secondarily to provide as much useful and suggestive information as possible.

IV

TRAFFIC AND TRANSPORTATION

In the broader sense transportation and traffic planning for an industrial plant involves not only materials handling, but the movement of personnel as well. This is emphasized because too often only the materials handling problems are given any appreciable attention in plant layout. The importance of traffic and transportation in relation to hazard may be inferred from a recent analysis⁴⁶ of industrial accidents. Classifying accidents according to mutually exclusive causes (i.e. each accident was classified under one cause only even though others may have a contributory effect) the report attributed 10.9% of industrial accidents to vehicles and 8.7% to hauling objects. Thus approximately 20% were entirely within the field of traffic and transportation. Other causes operating partly within the field accounted for percentages as follows: handling of objects, 25.9%; falls to a different level, 8.7%; falls to the same level, 9.5%; stepping on or striking against objects, 5.6%. These figures check substantially with those reported by other authorities.⁴⁷

Because movement of personnel and material is less regular and more difficult to standardize than production operations, the hazards which exist in connection with those functions are more easily overlooked.

⁴⁶T. A. Burke, "Safety," Plant Operation Library - 1946, Factory Management & Maintenance, New York: p.S-289.

⁴⁷H. W. Heinrich, op. cit., p.412.

For this reason particularly careful attention should be devoted to the problem during the layout stage of factory planning. Three interrelated aspects of traffic and transportation should be thoroughly investigated.

1. Movement of personnel
2. Flow of material - route planning and related problems
3. Mechanical handling methods and equipment

MOVEMENT OF PERSONNEL

Since the maximum volume of traffic will occur at the beginning and end of shifts, at rest periods, and during the lunch hours, primary attention should be concerned with the direction and size of these movements at various points to forestall areas of congestion or "bottle-necks." Bottlenecks present a two-fold hazard. Congestion in itself is an obvious hazard, and in the event of an emergency is a condition conducive to panics. However, bottlenecks are also the basic cause of accidents due to employees rushing to "beat the crowd." Accidents at stairs, elevators, and blind corners most frequently result from haste in addition to the physical hazard. Places to check for congestion are:

1. Time clocks and check-out stations
2. Regular and emergency exits
3. Stairs and elevators
4. Doorways and other openings having width less than that of the approaches thereto
5. Locker, cloak, and wash-rooms
6. Tool cribs

Many of these peak traffic problems can be alleviated in large plants by staggering shift changes, rest periods, etc. This, of course, is a matter of policy beyond the control of the layout engineer alone. Yet the policy must be determined before adequate plans can be made. Large aisles laid-out for materials handling equipment may be used for peak load movements of personnel.⁴⁸ In some plants, however, shift changes and rest periods are the times when material banks are built up at machines and assembly lines. This again is a matter which must be decided before adequate traffic planning can be attempted.

If peak traffic requirements have been provided for the movement of personnel during working hours it is not likely to cause congestion. There remains, however, the problems of excluding personnel from certain hazardous areas, preventing the crossing of materials-handling routes where visibility is inadequate (or improving the visibility), providing safety lanes for pedestrians in heavily traveled routes,⁴⁹ and guarding against slips, falls, stumbling, and striking against objects.

Passages, Walkways, and Stairs. The general rule that there should be no obstructions or stumbling hazards and that sufficient overhead clearance should pertain for the full width of any traffic-way is obvious. Yet a specially interested observer can find abundant violations. Gusset plates on overhead girders, overhead plumbing, horizon-

⁴⁸Dwight McCracken, "The Traffic Engineer Studies the Plant," National Safety News, 54:10, July, 1945.

⁴⁹Loc. cit.

tally projecting valves, fuse boxes, horizontally-hinged windows opening into corridors, and many other hazards may be found. Though any list is almost certain to be incomplete, an enumeration of some of the common hazards may stimulate a search that will lead to the discovery of others as well. The following check points were compiled as a result of personal observations of a number of plants and reference to published articles describing specific conditions in various plants and to texts on industrial safety.^{50,51,52,53}

1. All plumbing and wiring should be flush with passage walls. Equipment which must be mounted in passages (such as emergency fire equipment, radiators, fuse boxes, etc.) should be recessed so as to present a flush wall surface. Visual warnings (Ex. Switch box doors painted with A.S.A. warning colors) should be plainly displayed whenever the equipment or a part thereof must project temporarily for servicing.
2. All overhead plumbing, equipment, or structural members should be so installed as to permit sufficient clearance for the full width of the aisle or passage.
3. Fire doors and other closures should permit use of the full passage width.
4. Stairways carrying the full traffic from an aisle or passage should be of at least the same width and preferably wider.
5. Straight stairways are best. When changes of direction are necessary a landing is preferable. Where landings are not used the tread width at the narrowest end should be not less

⁵⁰"Safe Walkways," National Safety News, 53:106, March, 1945.

⁵¹"The Floor Underfoot," National Safety News, 55:89, March, 1946

⁵²Industrial Power Departments, (General Safe Practices Pamphlet #96), National Safety Council, Chicago.

⁵³R. P. Blake, op. cit., pp.229-232.

than standard width. Narrow bands of high visibility contrasting paint along risers of top and bottom steps and along the edge of the top step diminish the possibility of stumbling.

6. Changes in floor level of one or two steps are highly undesirable. If they cannot be avoided, ramps of gradual slope ($7\frac{1}{2}$ to 10°) are preferred to steps.
7. All shafts and other points of elevation change should be guarded by rails and a strip of high visibility paint along the edge. Kick-boards or curbs may also be advisable.
8. Floors should have anti-slip surfaces.
9. Provision should be made so that oil or other liquids cannot accumulate on aisle floors. A curb may be sufficient to keep aisle floors clear, but in extremely troublesome locations it may be necessary to install steel-grill flooring.
10. Manholes, drains, etc., should be offset from aisles.

FLOW OF MATERIAL

Fundamentally a manufacturing plant exists solely for the purpose of receiving material, changing its form utility in some manner, and shipping out the product. Generally speaking, the most successful plant is that which processes the greatest quantity of material for a given effort and investment in facilities. Many plant managers have found that plant capacity could be increased by the installation of new machines with higher rates of production at little or no increase in floor space requirements. However, the flow of material frequently proved to be a bottleneck. The same supply of material in terms of days or weeks of production requirements could not be maintained - even by drastic overcrowding of storage facilities. And attempts to accelerate the flow of materials could be likened to driving an automobile at high speeds on a wagon road - highly conducive to property damage and personal injuries.

Aisles laid out for hand-truck use are inadequate for mechanized equipment. Aisles laid out for light slow-speed equipment are inadequate for high-speed heavy-duty handling equipment. Materials storage and handling, therefore, in addition to their immediate importance are probably the most important factors in plant layout from the standpoint of potential future expansion. In this connection it is worthwhile to note that seldom must the quantities of material handled approach 100% utilization of mechanical equipment in order for that equipment to show savings as against manual handling of material. Mechanical equipment will be considered later in more detail; it is mentioned here only to suggest that present and future possibilities of mechanical handling in order to meet increased volume of handling accompanying expansion require recognition in the planning of the system.

Excepting conveyors, where the path is exactly pre-determined by the equipment and the movement largely automatic, the problem of material transportation is in many respects similar to traffic problems in urban areas. Low visibility, heavy traffic, intersections, and narrow right-of-ways are all potential hazards which reduce safe speeds and create congestion. Many of these problems may be approached in a manner similar to highway traffic planning, according to a prominent authority on highway engineering who has investigated industrial problems:

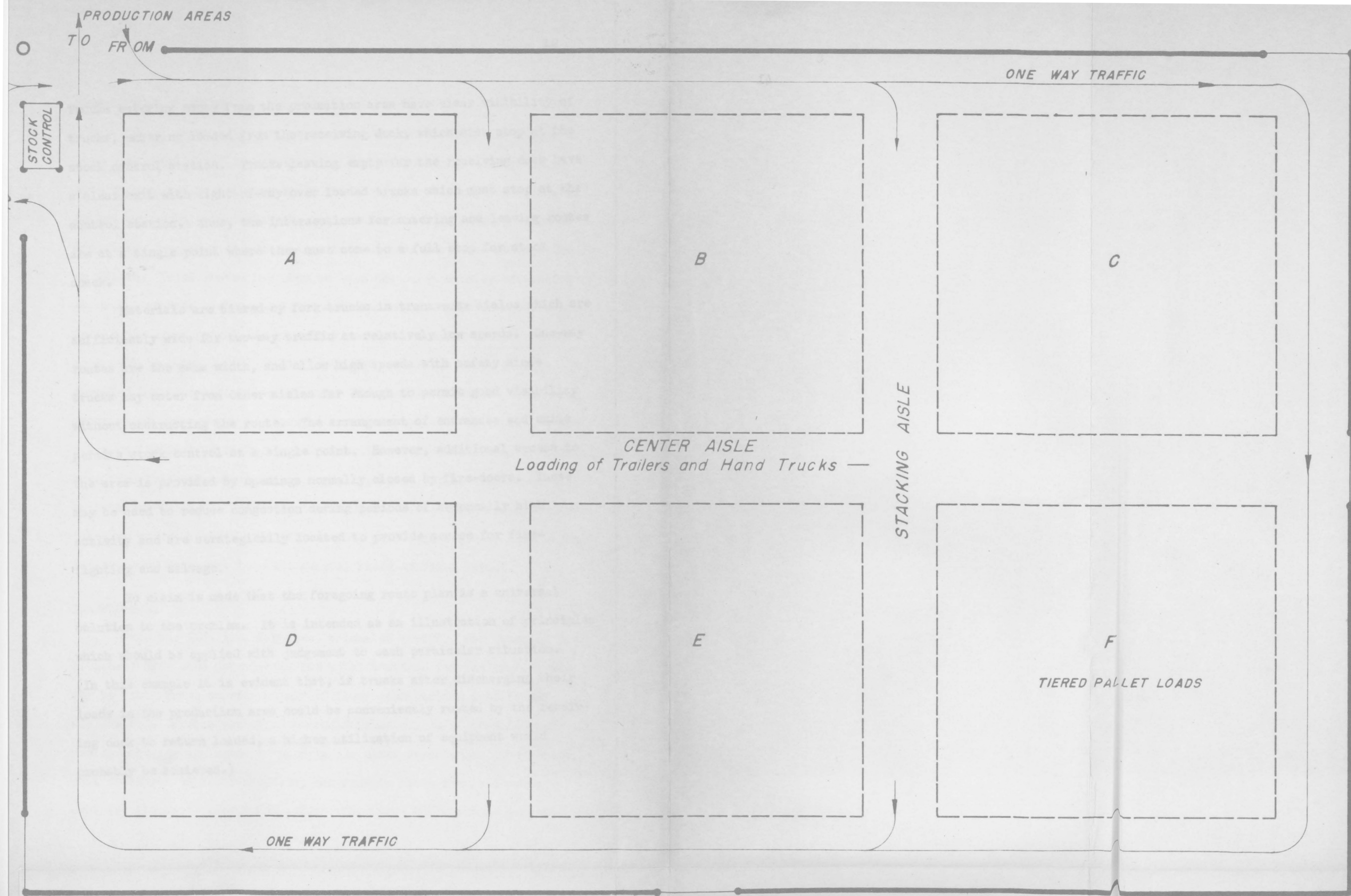
"Traffic engineering techniques which have been applied successfully to the problems of street and highway traffic can be used with equal effectiveness in overcoming congestion and hazards in plant aisles and connecting driveways between buildings."⁵⁴

⁵⁴Dwight McCracken, op. cit., p. 10.

The following points may serve as useful checks:

1. Reduce obstructions to provide for maximum visibility.
2. Eliminate blind corners wherever possible.
3. Where blind corners cannot be eliminated provide warning signs and/or signals, increase illumination and install mirrors.
4. Make sure that adequate clearances are provided on all traffic routes.
5. Use low curbs or durable markings to delineate traffic aisles clearly.
6. Establish thru-routes where large quantities of material must be moved and make sure they are identified as such.
7. Establish one-way routes wherever possible and especially where traffic is heavy.
8. In so far as possible locate intersections near check points, call stations, or other locations where equipment would normally slow down or be stopped for some purpose.
9. Provide adequate loading space to keep equipment off thoroughfares when not actually transporting material.
10. Where extremely large quantities of material are handled the consideration of traffic control lights at certain points may be warranted.
11. In yard operations involving considerable activity grade separations have been considered advantageous in several instances.

Several of these principles (in application to traffic in a storage area) are illustrated by Figure 1, page 41. Note the use of the central aisle as a fire lane and as loading space for hand trucks and motor-drawn trailers in order to keep them off the thru-route, which is a one-way aisle around the outer part of the storage area. The location of the right-of-way route around the outside wall minimizes the possibility that persons will cross the path of moving vehicles.



TRAFFIC ROUTING IN A STORAGE AREA

Figure 1

Trucks entering empty from the production area have clear visibility of trucks, entering loaded from the receiving dock, which must stop at the stock control station. Trucks leaving empty for the receiving dock have a clear exit with right-of-way over loaded trucks which must stop at the control station. Thus, the intersections for entering and leaving routes are at a single point where they must come to a full stop for stock check.

Materials are tiered by fork trucks in transverse aisles which are sufficiently wide for two-way traffic at relatively low speeds. One-way routes are the same width, and allow high speeds with safety since trucks may enter from other aisles far enough to permit good visibility without obstructing the route. The arrangement of entrances and exits permits stock control at a single point. However, additional access to the area is provided by openings normally closed by fire-doors. These may be used to reduce congestion during periods of abnormally high activity and are strategically located to provide access for fire-fighting and salvage.

No claim is made that the foregoing route plan is a universal solution to the problem. It is intended as an illustration of principles which should be applied with judgement to each particular situation. (In this example it is evident that, if trucks after discharging their loads in the production area could be conveniently routed by the receiving dock to return loaded, a higher utilization of equipment would probably be achieved.)

TRAFFIC FLOR DIAGRAMS

A useful device for route planning is the traffic flow diagram. It may be constructed most simply on a basic floor plan with pick-up and delivery points being drawn in first. Types of equipment operating to and from each point should be indicated along with quantities of materials, frequency of deliveries, time of peak load, and destination or origin. Trial routes may then be laid out on an overlay of tracing paper. Alternate routes should be analyzed on the basis of the previously discussed principles of safety and upon economic bases. Excessive back tracking due to faulty layout of production areas will be revealed by the traffic flow diagram. This may indicate the need for a revision of the process or production area layout and, of course, a new start on the traffic flow diagram. Sometimes back-tracking to a storage area used for both materials and work-in-process may be reduced merely by better scheduling. Although the reduction of handling in any manner tends to reduce hazards, the factors just mentioned begin to lead beyond the scope of this work into the general field of Plant Layout.

TRAFFIC-WAYS

Once the location of routes, volume of traffic, and types of equipment have been determined, the specifications for the traffic-ways may be set. These consist mainly of floor construction details and aisle width. Floors are often a considerable source of trouble when modern handling equipment is used in old plant structures. The speeds, unit pressures on floor surfaces, and dynamic loads involved pound ordinary floors to pieces and set up vibrations which become progressively

worse as the floor deteriorates. Substantial flooring with adequate structural support is the only permanent solution. New plants should be designed with these factors in mind.

Estimates of static floor loads exerted by fully loaded fork trucks are offered as a general guide in Table I immediately following.

TABLE I

FLOOR LOADS EXERTED BY FORK TRUCKS

Truck Capacity (Pounds)	Floor Load Exerted By Fully Loaded Truck (Pounds per Square Foot)
2000	260
3000	280
4000	320
5000	340
6000	380
8000	440

Source: Martin & Roberts⁵⁵

These estimates are useful as a guide, only, and not as design loads, since: 1) They do not include a safety factor, and 2) They do not account for dynamic loadings and vibration.

The unfortunate tendency to "economize" on aisle width has been

⁵⁵A. J. Martin and J. F. Roberts, "Planning The Pallet System," Plant Operation Library - 1947, Factory Management & Maintenance, New York: p.80.

commented upon in an earlier chapter.⁵⁶ If this writer has been at all successful, however, the necessity for adequate clearances to reduce hazards and promote efficiency should be established. It is strongly recommended that no aisle be less than five feet wide, and where mechanical equipment is to be used not less than ten feet. Table II summarizes the recommendations of two authorities for aisle widths to permit efficient operation of fork trucks.^{57,58} The second column indicates the minimum width for stacking aisles where stacks are at a 45° angle instead of 90° to the aisle. It is claimed that such a method of tiering speeds handling since trucks need turn only 45° from the direction of travel to pick up or place a load. If, however, for any reason the fork truck must turn around to make the return trip the apparent advantage is lost.

TABLE II

MINIMUM AISLE WIDTHS FOR FORK TRUCKS

Truck Capacity (Pounds)	Aisle Width (Inches)	
	90° Stacking	45° Stacking
2000	120 - 127	112
4000	144	124
6000	168	144

⁵⁶Supra, p.12.

⁵⁷A. J. Martin and J. F. Roberts, op. cit., p. 77.

⁵⁸H. E. Stocker, Materials Handling, " New York: Prectice-Hall, Incorporated, 1945. p. 96.

A rule of thumb advocated by some practitioners is to allow six feet plus three^{feet}/for every ton of load. It may be noted that the figures in column for 90° stacking follow the general pattern of eight feet plus two for every ton of load. No value selected from a table or by rule-of-thumb formula may be considered safe, however, unless checked against manufacturers specifications of turning radii of the equipment to be used with an allowance for clearance.

MECHANICAL HANDLING METHODS AND EQUIPMENT

The mechanization of materials handling will usually reduce hazards in certain well-defined ways.⁵⁹ For in man-handling materials a relatively large amount of common labor is necessary. And where the volume of material to be handled is large, congestion is usually the result. This is one element of hazard. Secondly, the probability of finding, in a group of men, some who are particularly apt to be involved in accidents is greatest when large numbers of men with low qualifications are hired. Both the numbers and the job requirements involved tend toward sketchy selection. Thirdly, there is less tendency to train common labor and with that a lower receptiveness to training which would improve their job performance from the standpoint of safe methods. Last, the higher the percentage of manual operations in any given job, the more difficult it is to standardize and assure conformity to the standard. The security of human grasping of a load, for instance, is altered by fatigue, slight variations in method, and diversion of attention.

⁵⁹Ibid. pp. 60-65.

In contrast, mechanization of handling reduces congestion. The use of a smaller number of workers, many with higher qualifications, permits a more careful screening in hiring. Men with higher qualifications are more apt to receive and are more receptive to training in safe work methods. They tend to be more stable and cooperative in following established procedures if properly explained to them. The reduction of manual operations and use of large unit loads permits a more particular determination of the cheapest and safest method with closer adherence to the standard once it is set. If properly engineered, the result is a well-secured load designed for positive mechanical grasping. The speed of mechanized equipment is a factor which, like larger unit loads, tends to reduce congestion and expedite handling.

Mechanization of handling, then, contributes to safety in at least four ways:⁶⁰

1. Fewer personnel, who are usually more intelligent and more carefully selected and trained.
2. Reduction of manual operations.
3. Handling of large, standardized unit loads.
4. Greater speed (less congestion.)

A realistic appraisal of mechanized materials handling must recognize, however, that some new hazards may be introduced as others are eliminated. Proposed methods should be studied in advance for possible hazards and equipment should include safety features such as

⁶⁰H. E. Stocker, op. cit., pp. 60-65

the following:⁶¹

1. Maximum visibility and protection for the operator.
2. Reliable braking and steering systems.
3. Guarding of moving parts.
4. Safety devices such as positive safety stops on all lifts and tilts, warning signals, deadman power cut-off, etc.

Speed is a potential hazard and may be a serious one if trafficways are not well planned.

Conveyors. In some industries the savings secured by adaptation to conveyORIZED materials handling have been tremendous. The small number of persons required for operation and the fixed path of movement also contribute to accident prevention. A few easily checked precautions against conveyor hazards should be observed, however.⁶²

1. Conveyors should be so guarded as to prevent personnel from crawling under or stepping over. (Installation should be high enough to allow overhead clearance or cross-over bridges should be provided as necessary for movement of personnel.)
2. Driving mechanism should be fully guarded.
3. Emergency stop controls should be provided wherever advisable.
4. There should be ample clearances at all points for the largest objects to be handled by the system.
5. There should be free access to all maintenance points.

⁶¹Industrial Power Trucks and Tractors, (General Safe Practices Pamphlet # 55), National Safety Council, Chicago.

⁶²Conveyors, (General Safe Practices Pamphlet # 35), National Safety Council, Chicago.

Elevators. Elevator hazards have been the subject of considerable specialized study sponsored by the equipment manufacturers and casualty insurers. The services of a staff consultant from a reputable firm of either of the above types can and should be obtained for assistance in planning elevator installations.

Other types of equipment. There is not space to consider each type of materials handling equipment in detail. In most traffic and transportation problems, however, clearance is a vital factor. An illustration from the writer's personal experience may serve to re-emphasize this point in concluding the chapter.

In the steel storage yard of a large industrial firm a diesel-powered crawler crane was used for materials handling. The 6,000 volt main power lines for the plant were carried in across the steel yard on towers, which, however were of inadequate height to provide clearance under the lines for the crane boom at its maximum elevation. On two occasions (one witnessed by the writer) the power lines were torn down by the crane. Fortunately, there were no injuries resulting from either accident. But on each occasion about a thousand men were idled for several hours. Ten thousand dollars would be a not unreasonable estimate of the costs of these accidents; yet, at the time the writer terminated relations with the firm there had still been no attempt to increase the height of the towers or re-route the line. Inadequate clearance had already cost that firm several times the expense of eliminating the hazard.

STORAGE FACILITIES

Too often it appears that storage facilities have been designed with little in mind beyond putting a roof over the materials to be contained therein. Sprinkler systems are becoming more common and have been installed in many older buildings largely through the efforts of insurance underwriters, and primarily because the reduction in rates usually pays the cost of the installation within three or four years. The tendency in new construction is increasingly toward fire-resistant construction with fire-walls sub-dividing the larger structures.⁶³ Thus the hazards of large-scale damage to material by fire or water are fairly generally recognized and controlled in some measure through the influence of insurers.

Though smaller in average amount, the losses sustained due to lesser hazards are greater in number and involve loss and damage to material, damage to equipment and building, and injuries to personnel. The hazards are sufficient to warrant a re-statement of the functions of storage areas:

1. To provide for the rapid and safe placing of materials.
2. To protect stored goods from major damage by fire or the elements.
3. To protect material from damage by excessive or abusive handling and from loss.

⁶³B. Hainsworth, "Warehouse Design and Construction," Factory Management and Maintenance, 105:B-70, April, 1947.

4. To facilitate control of stock and the taking of inventories.
5. To facilitate location of stock and filling of requisitions, shipping orders, etc.
6. To store materials in such a way that they will not be a hazard to employees working in the storage area, or to the entire plant and its personnel (fire hazard).
7. To provide for the rapid and safe removal of material in storage.

Not all these functions, of course, are equally significant from the standpoint of hazards. But even in such an operation as taking inventory the poorly planned store-room - where men must lift, turn, or move material in order to check it - present greater hazards (muscular strains, injuries due to dropped objects) than the well-arranged warehouse where all markings are clearly visible and counts may be taken without moving material. In fact, inventory-takers are likely to attempt tasks that experienced handlers would not undertake without mechanical equipment.

There are certain basic decisions which must be made before the planning of the storage facilities can begin - that is, if the effort is not to be wasted. In planning a layout for an existing structure some determination of the space which can be allotted for the storage areas must be made. Also there should be a definite indication whether - if the allotted space proves to be insufficient - the construction or renting of additional space is preferred. Though apparently irrelevant at this point the recognition of the possibility by higher officials will prevent its coming as a surprise at a later date and lessen the pressure to trim aisles and other necessary working space in order to "make" the

available space do the job. In designing new plants the same decision may be faced relative to accomodating peak storage loads. First/^{costs} and overhead costs appear to favor the renting of space for peak seasonal loads. It should be pointed out, however, that in the experience of some firms reduced handling costs have more than offset the expense of providing the additional storage capacity within their own plants.⁶⁴ An additional point in favor of the latter ~~alternative~~ is that expansion of the normal rate of activity without over-crowding or new construction is possible. Another set of circumstances where the renting of storage space may be desireable will be discussed later in reference to materials which require special storage conditions.

BASIC INFORMATION FOR PLANNING

The first step in the actual planning of storage facilities must be a determination of the quantity and turnover, size and type of packaging, and the variety of materials to be stored. This information will, of course, be the best estimate that can be furnished by the production-planning and purchasing departments. Systematic planning of the facilities will probably be expedited by the use of a worksheet such as suggested in Figure 2, page 53. Space is provided not only for basic information and the preliminary calculations but also for entry of nearly all the final details of the plan except the actual layout.

⁶⁴W. S. Wheeler, "Economical Handling in a Warehouse," Factory Management and Maintenance, 105:127, June, 1947.

ITEM	DESCRIPTION	SPECIAL STORAGE CONDITIONS	MAXIMUM QUANTITY TO BE STORED
Oil	Raw Linseed	(Combustible) Fireproof & Sprinklered Area - Segregated * Water-Fog type	5500 gallons

TURNOVER	PACKAGE DETAILS			STORAGE DENSITY	STACK HEIGHT
	Type	Size	Weight		
550 gals. per day	Steel Drum	55 gal.	430 #s	45 #s/A ³	12 ft.

STORAGE METHOD	STORAGE EQUIPMENT			TOTAL FLOOR AREA
	Type	Size	Quantity	
Palletized loads 1 drum high	Steel Pallets	48" x 48"	25	88 ft ²

FIGURE 2

WORKSHEET FOR PLANNING STORAGE FACILITIES

SPECIAL STORAGE CONDITIONS

The information furnished by the purchasing agent and production-planning engineer will rarely be sufficient for a thorough study of storage requirements, and this is especially true in regard to hazards. If there is any possible doubt, the properties of the material should be investigated and consideration given to special requirements for the storage of corrosive, combustible, and perishable goods. The latter property may involve only a matter of deterioration^{er} of quality, the prevention of which requires special conditions of temperature and humidity and not presenting any particular hazard. This is not the case with corrosive and combustible substances, and some tragic disasters have resulted largely from ignorance of proper storage and handling methods. Such ignorance was determined to be the basic cause of the Texas City Disaster after a careful investigation by experts.⁶⁵ As an example of what may be required in the way of special storage conditions it may be of interest to examine the recommendations for the storage of ammonium nitrate (the substance involved in the initial fires and explosions at Texas City):

"Material should be stored only in masonry or fireproof sprinklered buildings on skids or pallets on concrete floors with at least one foot clearance from walls. Storage should preferably be in separate fire divisions from highly combustible commodities.----Piles of ammonium nitrate in paper bags in storage should not exceed 10 bags (bags to meet the requirements of the Consolidated Freight Classification) high, 6 bags wide and 30 bags long with 3 foot separation between piles and with handling aisles of 10 feet every 100 feet."⁶⁶

⁶⁵Texas City, Texas Disaster, Special Joint Report; Fire Prevention and Engineering Bureau of Texas - Dallas, Texas - and The National Board of Fire Underwriters - New York.

⁶⁶Ibid. p. 44.

Data on specific materials may be obtained from the National Safety Council and The National Board of Fire Underwriters. Fire and Casualty insurers also circularize information and several excellent articles have been published on the subject.⁶⁷ In general, special storage conditions will increase the floor area needed through the necessity of segregated areas, greater-than-normal clearances, and less-than-normal stacking dimensions. Requirements such as these might create a situation where it would be cheaper to rent space in a warehouse specializing in the storage of the particular material. Where land is available it is definitely wise to plan for the erection of a separate building at a safe distance from the main plant when the hazard is particularly great. It is mandatory for the storage of explosives around mines and quarries.

The storage of combustible materials in bulk (bins, elevators, or outdoor stockpiles) also presents special problems. The hazards represent the two extremes of combustion - explosions and spontaneous ignition. An explosion may occur when the dust of a combustible substance in air-borne suspension reaches a certain concentration. Wetting-down is impractical as it fosters spontaneous combustion and may impair the quality of the material. Among the effective safeguards are magnetic separators to prevent the introduction of spark-producing objects into the storage space, Underwriters' Approved non-sparking equipment, and ventilation to hold the concentration of dust below that of the explosive mixture. An effective technique, when applicable, is the introduction

⁶⁷A. Korkelak, "Chemicals That Cause Trouble," National Safety News, 55:37, May 1946.

of an inert gas to prevent explosions by lowering the oxygen concentration below that necessary to support combustion.⁶⁸ The National Board of Fire Underwriters has conducted considerable research relative to dust explosion hazards, and their standards are a valuable guide.⁶⁹

Spontaneous combustion results from the accumulation of heat due to the slow oxidation of a substance until the kindling point is reached. In small concentrations of the material the heat is dissipated fairly rapidly and the temperature rarely reaches a critical point. One technique for controlling the hazard, then, is storage of the material in numerous small piles or bins to permit more rapid dissipation of heat. This also facilitates extinguishing any small fires that may kindle. Electronic smoke detectors are valuable for indicating the presence of even a minute blaze, and instruments for measuring the temperature of the interior of a pile reveal an approach to the danger point. Other methods have been devised on the same principle of preventing the critical accumulation of heat. Ventilation is one of the means, and within recent years cooling by chilled water or brine circulated through coils in the middle of the pile has been successfully applied to grain storage.

⁶⁸Regulations for Inert Gas for Fire and Explosion Prevention, National Board of Fire Underwriters, Pamphlet No. 12.

⁶⁹Standards for the Prevention of Dust Explosions, National Board of Fire Underwriters, Pamphlet No. 61, March, 1940. Although, developed with respect to starch factories, terminal grain elevators, and flour mills certain sections of these standards have general applications. Particular reference is made to the sections on Control and Removal of Suspended Dust, Removal of Static Dust, Prevention of Ignition, Mechanical Precautions, Electrical Equipment, Structural Features of Buildings, and Fire Protection.

STORAGE DENSITY

Storage density is defined as the volume of space occupied by the unit package in storage divided by the gross weight of the package, and is expressed in pounds per cubic foot. It is not necessarily a constant for a particular material - as distinguished from physical density, which is a fundamental property. For example, the storage density of oil stored in drums standing on end in aligned rows differs from the storage density of the same material in square containers, or in drums stored in staggered rows. In the first case the storage density would be the volume of the solid having a square base with side equal to the diameter of the drum and height the same as the drum divided by the gross weight of the drum of oil. Storage density may sometimes be obtained by reference (Table of Storage Densities, Appendix A), but in most cases must be calculated. If the physical density is used by mistake in storage calculations the error will obviously be on the side of safety. But if a lower than actual storage density is used as the basis a serious overloading of equipment or floors might result.

FLOOR LOADING AND STACK HEIGHT

One of the most frequently overlooked or ignored safety limits is that of floor loading. While elevators are periodically checked by city or state inspectors and the load limits posted where they cannot be excusably neglected, the safe floor loads of many commercial and industrial buildings are not even known to their current owners or tenants. While not everyday news, the collapse of a building is not an extraordinary item in our newspapers. In other cases the overloading results merely in

accelerated depreciation and forced abandonment of the property through condemnation or impossibility of use before expiration of the normal life of the structure. From any point of view overloading is hazardous and uneconomical. There is not space, nor is the writer qualified, to discuss in detail the determination of safe floor loads; it is a job for an experienced structural engineer. Original design data is of little significance when a building has sustained depreciation. A determination of safe floor loads on current state-of-structure basis by a qualified engineer is essential.

The problem of floor loading limits deserves far greater attention than it has received in recent years, since the development and rapid adoption of palletized storage methods and powered fork trucks now permit stacking to substantially greater heights than were formerly feasible.⁷⁰ A serious overloading is created when the pallet method

⁷⁰The pallet method of storing, handling, and shipping materials has probably received more attention in current writings than it warrants. Its popularity is probably due to the tremendous success achieved in the use of the method by the Armed Forces in World War II. It has never been pointed out, however, by enthusiastic proponents of the system that success in its utilization by the Armed Forces was due largely to certain medium-sized establishments. These special conditions were:

1. Tremendous quantities of goods were handled.
2. The Armed Forces were in a position to standardize the packaging of similar articles made by different manufacturers.
3. The Armed Forces standardized certain dimensions and multiples thereof in the packaging of different articles so as to obtain optimum pallet patterns.
4. The Armed Forces were in a position to utilize complete palletization because they controlled the product from the floor of the manufacturer's plant all the way through to the point of consumption.
5. Speed of handling was a paramount consideration, even if obtained at increased cost.

is introduced in plants where the floors were designed on the basis of loads developed by stacking only to heights which are practical with manual labor. The calculation of the maximum permissible stacking height, then, is one of the most vital computations in planning storage facilities. To reduce the time and labor involved in determining the height of tiering the writer has devised a graphical means of solution, which is presented in Appendix A together with a sample problem illustrating the method of solution and a table of common storage densities. (Because of the variability of storage density, however, it is recommended that each firm compile its own table). The graphical device has a further use in planning pallet systems in that, when the pallet size is selected and the safe pallet load for the handling equipment determined, the required number of pallets per stack is immediately indicated.

It should be pointed out that a variable error occurs in the determination of stack height by this method. The average pallet has a density of around 10 to 12.5 pounds per cubic foot and is six to nine inches thick. Hence, for all materials with a density greater than 12.5 pounds per cubic foot (and, to the writer's knowledge, practically no commercial or industrial materials have a density less than that) an

The last point may seem to be a contradiction to the usual claim that the pallet method is faster and cheaper. The answer is - sometimes. The Kellogg Company, for instance, found that although pallets were the answer to their warehousing problems they were not economical for shipping. The speed gained in loading cars was more than offset by the cost of shipping space lost through the use of pallets (See reference cited in footnote 64). In other words, the pallet system has limitations which have not been publicized as widely as its advantages.

error on the side of safety will be introduced. That is, the true maximum stack height (including the pallet) will be somewhat greater than the indicated value. For most materials the error is not appreciable, but for extremely dense substances it is desirable to make the direct calculation including the pallet or to make a correction by means of the following formula:

$$\text{Stacking Height} = \text{Indicated height} \div \text{pallet thickness} \times \frac{\text{Pallet density}}{\text{Material dens.}}$$

OTHER LIMITATIONS TO STACK HEIGHT

Three other factors may operate to reduce the permissible stack height below that determined on the basis of floor loadings. The stability of the stack, determined by the nature of the package and method of stacking is one limiting factor. A second factor which especially limits the stacking height of low-density materials on sturdy floors is the overhead clearance. An absolute minimum of six inches clearance should be allowed on overhead girders, conduits, fixtures, etc.. A final consideration is the minimum overhead clearance for proper operation of sprinkler systems, if one is installed or contemplated. Competent advice should be secured on the clearance for the particular type of head used; and that clearance should be strictly observed. One of the leading factory management periodicals recently published⁷¹ a photograph of a modern materials handling and storage installation - detailed examination of which showed pallets stacked so close to sprinkler heads that they

⁷¹"Two-Way Radio Speeds Palletized Storage," Factory Management & Maintenance, 104:127, August, 1946.

could not possibly have operated effectively. Yet the management of that company probably felt secure in the thought that they had controlled the fire hazard in their warehouse.

METHOD OF STORAGE

The best storage method may often have but a narrow margin of advantage over some alternative method, and a change of one factor may entirely reverse the situation. Unit handling costs on one particular item, for example, might be lowest when a two-ton pallet load is used. If the quantity of the item handled were not great, however, and other unit handling loads were no larger than one ton the cost of additional equipment capacity and wider aisles for its operation would not be warranted. Most of the information provided on the worksheet (Figure 1, page 40) is essential to the selection of the best storage method. From the standpoint of hazards the particular method used is generally not so important as the equipment and proper application of the method. One general restriction which should always be observed is that no part of the storage unit be allowed to extend beyond the vertical projection of the base; that is, there should be no over-hangs. This is necessary for stability and to reduce the hazard of head and other injuries.

Small Items. ⁷² Probably the three most common methods of storing small items are open, closed, and bin-front shelving. Cabinets are occasionally used for items that require special protection from

⁷²L. P. Alford and J. R. Bangs, Production Handbook, New York Ronald Press, 1946. pp. 425-431

pilferage. Two other methods are of particular value in job order plants and small lot manufacturing. The bin rack for removable bins is made both in counter height and larger units. Large bin boxes have an interlocking feature for stacking one on another to make up units of any desired proportions. The advantage of this method for the applications mentioned is that stock may be re-arranged without individual handling of pieces, and the likelihood of injury to personnel or damage to material is thus reduced. Handling of special parts may be further reduced by placing the bins in a special rack truck and wheeling them to the assembly point as a complete dispensing unit containing all the small parts necessary for a particular product.

Most of this equipment can be satisfactorily fabricated out of wood in plant maintenance shops, or standard units made of sheet steel can be purchased. Though the first cost will usually be higher the steel units have distinct advantages, including safety:

1. Standardization
2. Flexibility
3. Durability
4. Maximum capacity
5. Strength
6. Safety (wood shelving is a source of splinters)
7. No fire hazard

Wood may be preferred for tool and gage racks, where its relative softness and property of absorbing moisture are advantageous. For other applications steel equipment is superior.

Bar Stock and Pipe. Material of this class should never be stored in loose piles on the floor. The minimum provision for storage should include some sort of structural frame to definitely retain the pile within a prescribed area. Though retained piles may be satisfactory for some applications, racks usually provide a more efficient use of space. Racks for the storage of long slender objects will fall into one of the following classes:

1. Portable racks which can be moved by hand platform-lift or powered handling equipment. Length limit of load - about 6'.
2. Wheeled portable racks which may be moved by hand or power. Size limited by aisle dimensions. Length limit - about 8'.
3. Permanent racks, enclosed or projecting arm type. No limit on length of stock.

The first two types offer the cost and safety advantages of large, well-secured unit loads for mechanical rather than manual lifting. Since racks are usually shop-fabricated it is pertinent to suggest that all exposed sharp corners and flame-cut or sheared edges be ground off. Where contact with personnel or equipment is likely it is recommended that those points be protected additionally by guards improvised from salvaged hose, tires, or similar material.

Cylindrical Objects. There are about four well-defined methods of storing cylindrical objects such as steel drums, barrels, and hogs-heads. Their acceptability from the standpoint of hazards is determined primarily by the method of handling to be used. These methods and their limitations are as follows:

1. Storage in retained piles with axis of container horizontal. Approved only when handling is by means of suitable mechanical equipment. Limited to two-high stacking if object is barrel-shaped.
2. Storing on end. Limited to one-high storage if manually handled. Stacking is permissible if mechanical equipment is utilized, and especially if dunnage is used to insure stability and facilitate placing of the lifting device.
3. Storing with axis horizontal in gravity-feed racks.⁷³ One-high limit per rack. Lower end must be at proper height to discharge on cradle dolly. Rack must incorporate a safety mechanism to prevent release of more than one container at a time.
4. Storage on pallets.⁷⁴ Cradle pallets permit storing with axis horizontal. Standard pallets require containers to be placed on end. Mechanical equipment is required for handling and stacking height is limited by factors previously discussed (pages 14-18).

Medium-sized Irregular Objects. Manual handling of this type of material usually presents a high risk of muscular strains and associated injuries. Skid or pallet boxes appear to be the best method devised for storage and handling. Both are adapted to moving with either hand or power operated equipment. The special skid box or rack with an axle and wheels at one end is especially adapted to hand movement with a compact lifting and steering dolly.⁷⁵ A recent improvement on the common skid and pallet boxes is the collapsible wire container which can be used for shipment as well as storage and handling within the plant. Use of these

⁷³L. P. Alford and J. R. Bangs, op. cit. p. 424.

⁷⁴H. E. Stocker, op. cit. pp. 75-79.

⁷⁵G. R. Kepner and W. T. Press, "Better Handling Nets Important Savings," Factory Management and Maintenance, 106:95, February, 1948.

containers by the Westinghouse Electric Corporation to reduce individual handling of motor and bracket castings resulted in fewer accidents and lowered handling costs.⁷⁶

A feature of the skid box often cited as a disadvantage in comparison with pallets is that greater space must be allowed under the box proper for entry of a platform truck than is required by a fork truck.⁷⁷ The wastage of space, however, is purely illusory when floor loading rather than ceiling clearance limits stacking height. And unless special platforms are provided at work-places for pallets, the skid box places material at a height more convenient to the operator. Skid and pallet racks permit the removal of any load in a stack without disturbing the remainder, an important factor in reducing congestion hazards where quantities of individual items stored are relatively small

⁷⁶G. R. Kepner and W. T. Press, op. cit. pp. 94-95.

⁷⁷It seems desirable at some point in this discussion to differentiate between skids and pallets. Nowhere in the literature on the subject has this writer been able to find a definition. The following, therefore, have only the authority of usage as interpreted by the writer:

Pallet - any type of platform, box, or rack designed to be handled by a fork-lift truck. In common usage "pallet" signifies a double-faced platform with a 4" to 7" space between faces or decks. Special types are usually designated as "rack pallets," "pallet Boxes," etc.

Skid - any type of platform, box, or rack designed to be handled by a platform-lift truck. In common usage "skid" refers to a single-faced platform with wood blocks or metal legs to support the platform about 9" to 12" off the floor. They may or may not be designed to interlock with other skids for stacking. Special types are identified by a descriptive name.

A point of confusion is reached when one attempts to distinguish a single-face shipping pallet from a shipping skid. For practical purposes there is, in fact, none.

and turnover is rapid.⁷⁸

Large Irregular Objects. Large objects of a shape which will not permit stable stacking are best stored in rack units.⁷⁹ Except for the fact that a rack instead of a box is used to retain the material other details of storage are the same as those discussed in relation to medium-sized irregular objects.

Bagged or Boxed Materials. Storage on flat pallets or skids is probably the best method where a number of moves are to be made with a large unit load. The size of the unit load is determined by equipment capacity and by stability. Other factors are similar to those discussed above.

Where only one move can be made with a large unit load and other moves will involve handling individual bags, boxes, or cartons, the pallet system is of dubious advantage. The material can usually be carried into the storage area by conveyors and delivered at the most convenient working height for stacking.⁸⁰ Delivery from storage may be made by gravity conveyor, and there is no problem of handling and disposing of empty pallets. From the standpoint of hazards there is little difference except that the palletized stack is somewhat more stable.

⁷⁸Norman Quigg, "Storage in Key Areas Cuts Floor Space 60 Per Cent," Factory Management and Maintenance, 105:125, August, 1947.

⁷⁹H. E. Stocker, op. cit. pp. 20, 107, 124.

⁸⁰Ibid. p. 137.

VI

PLANT SERVICES

Plant services are considered here as those functions and facilities which are necessary, in a physical sense, to the operation of a plant without taking a direct part in the production process. They are distinguished from employee services (to be considered in the following chapter) which supply the various human needs within the plant. The detailed planning of plant services, with the possible exception of maintenance and repair facilities, is not within the province of the industrial engineer. He may, it is true, have to determine the services which must be rendered and the general conditions thereof (such as the quantity and quality of process steam required, or a detailed schedule of electric power requirements) but the actual design and planning of power plants, distribution systems, etc., is performed by specialists.

Since plant services are much less varied from industry to industry than production processes and other plant functions it has been easier to set up broad standards for the control of hazards. Most of these can be obtained from fire and casualty insurers. These firms also maintain staffs of experienced engineers whose services are available to policy holders and are invaluable in checking proposed installations for hazards.

A brief discussion in general terms, therefore, should be sufficient from the standpoint of the industrial engineer. Of all plant

services, power supply is particularly a specialized problem. At the least, structures housing power supply facilities should be separated from the remainder of the plant by a firewall - if not completely detached (which is desirable in some special cases). With the isolation provided, the problem may be considered as an entirely separate one from the general design and layout problems. If electric power is purchased, the plant engineer must determine the minimum overhead clearance for main power lines according to the yard equipment to be used. Contracts for power plants and power supply equipment (transformers, etc.) and the installation thereof should require conformity to an approved safety code.

Distribution systems. Distribution systems are the means by which electric power, steam, compressed air, other gases, and liquids are conveyed to points of use throughout the plant. Here again the details of planning and the installation are usually sub-contracted. However, there are several important safety factors which should be checked by the plant layout engineer:

1. Adequate clearances and (where necessary) special protection of the system against mechanical injury should be provided.
2. There should be easy access to the system for maintenance and repair.
3. All pipes, conduits, etc., should be clearly identified.
4. Controls should be conveniently located, guarded against mechanical injury, and (where necessary) protected against unauthorized operation. Directions for operation should be posted in a conspicuous place.

5. The system should be planned for flexibility and adaptability to layout changes to eliminate the necessity for flexible hoses and electric power cables except where required, due to vibration of equipment or for portable tools.

Maintenance and repair facilities. Maintenance and repair shops can be the most hazardous areas within a plant. Often skimped for space because they do not perform a directly productive function, the variety of operations performed leads to a potentially large group of hazards. The majority of those hazards have already been considered in Chapter III, Production Areas. It may be useful, however to mention a number of the most frequently needed control measures:

1. Space provisions must be sufficient not only for the safe and efficient operation of shop equipment but also to accomodate and allow free access to the largest equipment which may be brought into the shop for servicing.
2. Electric power distribution systems must be adequate for the maximum loads (load may vary greatly in repair shops) and should provide numerous outlets for portable tools.
3. Particular care should be exercised to provide for good housekeeping, especially the removal of trash and scrap (many repair shops are more notably deficient in this respect than in any other.
4. There should be proper facilities for the safe storage and use of paint, solvents, lubricants, and other flammable substances.
5. Working conditions (discussed in detail in the following chapter) should be stressed as much as they are in any other part of the plant. Ventilation must be planned on the basis of the worst conditions which might occur.

VII

EMPLOYEE FACILITIES AND GENERAL WORKING CONDITIONS

The hazards discussed in preceding chapters might be defined as direct hazards; that is, they are proximate and sometimes the only causes of accidents. To complete this analysis it is necessary to consider a group of factors which could well be termed "indirect hazards." Some, such as improper illumination or excessive noise, may prevent an employee's awareness of a major hazard. Acting in this way an indirect hazard may be a 'sine qua non' link in the accident causation chain. In other ways, these indirect hazards have a more insidious effect. Through fatigue, lowered morale, and impaired health they drain away the industrial worker's production efficiency and create a psychological and physiological state in which the employee is more likely to become an accident victim. Among indirect hazards may be cited such factors as:⁸¹

1. Improper Posture, working position
2. Excessive Noise
3. Vibration
4. Heating, Ventilation, and Air-Conditioning
5. Food and nourishment
6. Sanitary Facilities and Wash Rooms

⁸¹"Fatigue - Thief of Time," National Safety News, 55:10-11, March, 1946.

7. Floors

8. Illumination

9. Painting of the plant interior and equipment.

The point may be raised that some of these are matters of long-term social policy and have nothing whatever to do with plant design.

However, if the object of plant design and layout is to achieve the most efficient producing unit then any facility which saves more than it costs is a vital factor in planning. Glancing over the list which has just been set forth it would appear that food and nourishment might be the factor least directly related to plant efficiency. Yet more and more new plant designs are including provisions for the preparation and serving of food to employees under sanitary and pleasant conditions.^{82, 83}

Fifty percent of the new plants described in detail in the 1948

Industrial Plant Buildings supplement of Factory Management and Maintenance Magazine include such provisions. With cost such a dominant factor in current production it is reasonably certain that such action was not inspired by purely philanthropic motives. In a discussion of current trends the following comments may be found in that same publication:

"The efforts of industrial management to increase the comfort and safety [emphasis added] of employees are significantly influencing new plant design throughout the nation. Shortage of labor, union requirements, and a generally more progressive attitude toward personnel have led to exterior beautification, adequate and attractive sanitary facilities, and, in general, a new concept of the employer-employee

⁸²M. P. Fox, "Cafeteria Big Factor in Lowering Costs," Factory Management & Maintenance, 104: 140-141, October, 1946.

⁸³H. G. Fromm, "The Beautiful Plant is More Efficient," Factory Management & Maintenance, 105: 76-79, November, 1947.

relationship. Firms employing large numbers of people seldom fail to provide parking areas, lunch rooms and cafeterias, and recreation space both in and out of the building. . . . companies are making substantial investments in well-equipped cafeterias readily adaptable for auditorium use in connection with training or recreation programs. In some instances, special outdoor promenades and terraces are being provided for relaxation with minimum expenditure through the utilization of otherwise idle roof areas."⁸⁴

Similar comments on new plant trends were made by the editors of the 1947 Industrial Plant Buildings supplement of Factory Management & Maintenance magazine:

"To make employees 'feel at home' while working, shower rooms are becoming more spacious; smoking rooms are provided at convenient points; conditioned air in locker rooms and ventilated lockers are widely accepted design features. Large-vision panels to bring an outdoor panorama to the inside of the plant are being incorporated even in glass-brick walls. Newly developed color codes guide painting to increase the safety, restfulness, and worker efficiency in many production areas.

A new feature found in many plants is the installation of germicidal lamps in cafeterias, kitchens, locker rooms, and traffic points to combat common colds and other air-borne bacteria.

Recreational facilities are very frequently coordinated with community facilities today. . . . Most new Plants provide in-plant food service facilities as a matter of course."⁸⁵

A review of the annual report of the Chief Inspector of Factories (G.B.) for 1941 indicates that much the same views have been held in Great Britain for some years:

"There is now a fairly wide recognition of the fact that adequate lighting and heating and the provision of amenities for employees are justified even on a purely money basis."⁸⁶

⁸⁴"Trends in Plant Design and Construction," Factory Management & Maintenance, (Part II, Industrial Plant Buildings), 106:B 46-47, April, 1948.

⁸⁵"Trends in Plant Design and Construction," Factory Management & Maintenance, (Part II, Industrial Plant Buildings), 105:B 44-45, April, 1947.

⁸⁶"Factory Conditions," Engineering, 154:371, November 6, 1942.

This rather extensive quotation of authorities has not been without purpose, for the idea that the majority of employee facilities are strictly luxuries has by no means completely expired. This tends to be particularly true in small manufacturing organizations. The management of such firms - often not many years removed from the "shoe-string" stage of development - is sometimes ultra first-cost conscious. A certain degree of caution, to forestall indispensable capital being frozen in non-productive ventures, is necessary for survival. On the other hand, the failure to adopt tested measures which increase the productive efficiency of labor and reduce costs (including accidents, lost time due to illness, etc.) may be a serious handicap in a competitive industry. A firm's financial position may be just as surely impaired through frugality as through extravagance.

One additional comment on the small plant problem seems appropriate. Measures which have proven effective in large plants may not be economically feasible (or may require modification) in small plants. Cafeterias, for example, are not likely to be practical solutions to the food and nourishment problem in plants employing under 100 persons.⁸⁷ A satisfactory solution will be suggested in the following section.

LUNCHROOMS AND SIMILAR FACILITIES

The matter of diet for industrial workers presents both short and long range considerations, since it affects both the productive

⁸⁷Lunchrooms For Employees, A Report of the Policyholders Service Bureau, Metropolitan Life Insurance Company, New York: n.d., pp. 6-9.

efficiency and the health of workers. It appears to be well-established that a well-balanced diet for in-the-plant meals can be insured only by offering the meals at a reasonable price within the plant (except in the rare instances where the requirements are properly met by public eating places of sufficient capacity located conveniently near the plant).⁸⁸

It also appears that the frequency of meals is an important factor in the short-term viewpoint due to its effect on output. Lighter noon meals with morning and afternoon "snacks" have proved effective in eliminating production slumps.⁸⁹ The following benefits claimed by one firm which installed a cafeteria to feed 325 employees in 4 shifts probably include all that could be hoped for from the installation of in-plant meal facilities:

- "1. Better plant housekeeping.
2. Fewer accidents.
3. Less absenteeism.
4. Lower labor turnover.
5. Improved supervisor-worker relationship.
6. Higher morale.
7. Healthier workers.
8. Better grade of job applicants."⁹⁰

⁸⁸Ibid., pp. 1-2.

⁸⁹H. W. Haggard and L. A. Greenberg, Diet and Physical Efficiency - The Influence of Frequency of Meals upon Physical Efficiency and Industrial Productivity, New Haven: Yale University Press, 1935.

⁹⁰M. P. Fox, op. cit., pp. 140-141.

A number of different methods of providing in-plant meals have been used successfully in various situations:

1. The Coffee Bar
2. The Rolling Cafeteria
3. The Canteen
4. The Lunch Counter
5. The Cafeteria

These are discussed in detail in the reference mentioned, which is available without cost to industrial firms.⁹¹ All but the last are practical for small plants (under 100 employees). In all cases it is important that a comfortable and sanitary place for the employees to spend their lunch hour be provided.

HEATING, VENTILATING, AND AIR-CONDITIONING

That temperature, humidity, and air-movement are definite factors in the health and comfort of people is well known. Air purity is also significant. The control of industrial air contaminants is obviously essential.⁹² Under normal conditions ventilation is required to supply fresh air for breathing and to remove air contaminated by smoking and by various odors.⁹³ These factors also have a direct effect on

⁹¹See footnote 86.

⁹²Supra., pp. 19-25.

⁹³B. H. Jennings and S. R. Lewis, Air Conditioning and Refrigeration, Scranton: International Textbook Company, 1944. p.76.

productivity.⁹⁴ The significance of air conditions in relation to accident causation has been summarized by one of the foremost Industrial Psychologists in Great Britain:

"Quite apart from the physiological effects of too high or too low temperatures or of stagnant air, anything which makes a worker feel uncomfortable attracts his attention to himself and therefore away from his work, and so is likely to involve him in an accident if circumstances provide the means."⁹⁵

The desirability of completely controlled atmospheric conditions within the plant is indisputable. To date, however, complete air-conditioning has not proved economically feasible except for offices, drafting rooms, and in some manufacturing rooms where the process makes it necessary. The trend in new plants is toward the installation of ventilation fan systems so planned that air-conditioning equipment may be added to the system at a later date.⁹⁶ Radiant heating was pioneered in the Johnson Wax Company plant in Racine, Wisconsin, nearly fifteen years ago with excellent results, and is now coming into considerable popularity. Three techniques for combating local extremes of air conditions are worth mentioning. Cold winter drafts from open passages, loading ports, etc., may be eliminated by directing the air-flow from a unit heater or high-velocity warm air outlet across the opening. The

⁹⁴Air Conditions and the Comfort of Workers, (Industrial Health Series - No. 5), Metropolitan Life Insurance Co., New York: n.d., p. 16.

⁹⁵May Smith, An Introduction to Industrial Psychology, London: Cassell and Company, Ltd., 1943. p. 180.

⁹⁶"Trends in Plant Design and Construction," Factory Management & Maintenance, (Part II, Industrial Plant Buildings), 106:B 46-47, April, 1948.

same principle is effective in protecting workers against exposure to convected heat from open-end ovens, furnaces, etc., by means of a high-velocity air curtain. Spot cooling of the worker by means of a cool air stream may eliminate heat exhaustion and increase productivity in a situation where the cost of general air-conditioning would be fabulous.⁹⁷

The degree to which optimum comfort conditions can be approached is a matter of balance between the benefits derived (increased productivity, morale, etc.) and the cost of securing them. Ventilation, however, must not fall below certain minimums for air purity; and temperatures so extreme as to constitute a direct hazard in themselves must be brought under control, usually by localized methods. The installation of the actual equipment has been discussed in general in Chapter VI and, specifically, should conform to the National Board of Fire Underwriters' Standards.⁹⁸

NOISE AND VIBRATION

Noise and vibration are generally related in that they often have a common cause in industrial plants. To the extent that noise interferes with the hearing of warning signals it is a link in the chain of accident causation. Noise is also a hazard to health

⁹⁷A. D. Brandt, op. cit., p. 283.

⁹⁸Air Conditioning, Warm Air Heating, Air Cooling and Ventilating Systems, (NBFU Pamphlet # 90), National Board of Fire Underwriters, New York: October, 1946.

in that it can produce deafness. However, the level above which noise becomes a health hazard has not been precisely determined. An intensity of 120 decibels is actually painful, while continued exposure to levels of 90 decibels and above appears to be definitely harmful.⁹⁹ There are some records of prolonged exposure to noise levels below 90 decibels causing deafness.¹⁰⁰ These figures become significant in relation to a table of noise levels produced by various types of machinery.

TABLE III¹⁰¹

NOISE LEVELS PRODUCED BY DIFFERENT MACHINES AT A DISTANCE OF 3 FEET

<u>Machine or Operation</u>	<u>Noise Level (decibels)</u>
Punch Presses	96-103
Drop Hammers	99-101
Bumping Hammer	100
Hydraulic Press	130
Automatic Riveters	95-99
Lathes (average)	80
Automatic Screw Machines	93-100
Aircraft Riveting Guns	94-105
Aircraft Propeller Grinding	100-105
Looms	94-101
Wood Planers	98-110
Wood Saw	100

⁹⁹D. McKenzie, "Noise and Public Health," Journal of State Medicine, 42:542, September, 1934.

¹⁰⁰"Effect of Noise on Hearing of Industrial Workers," State of New York Department of Labor, Special Bulletin 166, New York: 1930.

¹⁰¹A. D. Brandt, op. cit., p. 323.

Other evidence indicates that nervous tension increases with noise and also that sudden changes in noise levels have an undesirable effect. The general conclusion reached from a study of the problem is that noise levels above 90 decibels or thereabouts required definite action. Noise levels from about 60 to 90 decibels are annoying, may have some effect on nervous tension, and should be reduced when economically feasible.

Fundamentally there are about four ways to handle the noise problem. Not all are equally satisfactory from the standpoint of ideal conditions but it is sometimes necessary to make compromises.

1. Eliminate the source of the noise.
2. Isolate the source of the noise.
3. Reduce the noise by acoustic methods.
4. Supply protective devices to personnel.

If the noise is due to unbalanced moving parts in equipment or to bad gearing or similar mechanical causes there is an excellent possibility that it can be eliminated. If the process is inherently noisy it may be necessary to isolate it from other operations in the plant. The workers who must tend such equipment, however, need some protection, of which the most common form is the ear stopper. If the noise level can be reduced sufficiently by means of sound absorption material it may not be necessary to isolate the process.

Vibration. With respect to hazards vibration is primarily of significance as a cause of noise. Mechanically, vibration is the result

of unbalanced rotational or reciprocating motion or some combination of the two. It is most desirable, of course, to minimize vibration through proper design. If this is not sufficiently effective, either physical isolation of the process or insulation by means of special foundations is necessary. The latter method has been developed to such effectiveness that physical isolation (i.e. a remote location) is no longer necessary. Jolt machines - weighing up to 11 tons with the jolt table and flask alone weighing as much as 5 tons - have been specially mounted with such success that laboratory instruments less than 50 yards away could be operated without interference.¹⁰²

FLOORS

The selection of flooring for the new or re-modeled plant should receive careful consideration. A detailed discussion does not seem to be necessary since the following list is a rather complete criterion for the evaluation of various types. Factors to be considered are:¹⁰³

1. Strength
2. Non-slip surface
3. Durability
4. Ease of Maintenance
5. Fire resistance

¹⁰²"Special Mounting Isolates Vibration," Factory Management & Maintenance, 105:135, June 1947.

¹⁰³"The Floor Underfoot," National Safety News, 55:89, March, 1946.

6. Personal comfort

7. Quietness

SANITARY FACILITIES, WASHROOMS, AND LOCKER ROOMS

Facilities of this sort can be completely justified on the basis of either health or industrial relations alone. Together they furnish a cogent reason for careful planning of the facilities. The trend is indicated in a current review:

"Modern washrooms using steel stall partitions, circular wash-fountains, and improved sanitary fixtures are being located as closely as possible to working areas. There is an increasing trend toward separating washrooms from locker areas. Toilet facilities can save money for the employer by being located at convenient intervals throughout the plant, instead of in one large room."¹⁰⁴

Other innovations are air-conditioned locker rooms and ventilated lockers. In one plant, where operations were necessarily dirty, a laundry service was provided so that employees would not have to carry dirty clothes out of the plant. Combined with adequate shower and locker room facilities this service enabled production workers to leave the plant clean and neatly dressed. The result was a considerable boost in morale and the removal of a stigma against certain types of work in that plant.

A remark should be made about the worst possible error that can be made in the planning of sanitary and similar facilities. The facilities

¹⁰⁴"Trends in Plant Design and Construction," Factory Management & Maintenance, (Part II, Plant Buildings), 106:B47, April, 1948.

must be adequate to handle the maximum load in a reasonable length of time. Few things can be more damaging to employee relations (or more contrary to good housekeeping principles) than over-crowded employee facilities. The capacity of the facilities is fully as important as the quality.

ILLUMINATION

Excepting the psychological effects of color, both lighting and painting relate to one fundamental requirement for efficient and safe operation of the industrial plant - good seeing. Obvious as the objective may appear, the factors controlling it are not so simple. Installation of 800 industrial type fluorescent lighting units in the plant of Graphlex, Inc. at Rochester, N. Y.,¹⁰⁵ failed to solve their seeing problems. Not until the location and mounting of fixtures had been redesigned and walls refinished with properly selected colors did the complaints of inadequate illumination cease. A needless expense was incurred through failure of the initial plan to recognize the fundamental factors.

The advantages of providing adequate illumination have been summarized by Brandt¹⁰⁶ and are substantially as follows:

1. Greater accuracy of workmanship, resulting in an improved quality of product with less spoilage and rework.

¹⁰⁵V. G. Rollins, "New Lighting, Fresh Paint Help Workers See Better," Factory Management & Maintenance, 104:140-142, March, 1946.

¹⁰⁶A. D. Brandt, op. cit., p. 298.

2. Increased production at lower costs.
3. Cleanliness and neatness more easily maintained in the plant.
4. Better utilization of floor space.
5. Greater ease of seeing, especially among older experienced employees, thus making them more efficient and permitting industry to continue utilizing their experience.
6. Less eyestrain among employees.
7. Improved morale among employees, resulting in lower labor turnover.
8. Greater safety.

A number of these advantages were realized in the case of an electric locomotive repair shop where increased illumination brought about a 10% increase in output, an 80% decrease in defective work, a 43% reduction in accidents which resulted in compensated injuries, and a 41% reduction in accidents involving lesser injuries.¹⁰⁷

It has been suggested that the factors affecting good seeing are not altogether simple. Even eliminating the physiological factors (which are beyond the scope of this discussion), there are at least five factors which influence visibility:

1. The light source
 - a. Intensity
 - b. Light distribution pattern
 - c. Quality
 - d. Location

¹⁰⁷ "What Better Lighting Did for One Shop," National Safety News, 53:78, March, 1946.

2. Light reflecting surfaces
 - a. Walls
 - b. Floor
 - c. Ceiling
 - d. Equipment
3. Range of illumination intensities
4. Glare
5. Color contrast

The most obvious property of lighting systems - and frequently the only one considered by inexperienced designers - is the general level of illumination. The unit of measurement is the foot-candle, and the values considered good practice today range from .2 foot-candles for artificial illumination of railroad receiving yards to 1000 foot-candles for hospital operating rooms.^{108, 109} Essentially, level of illumination is the composite effect at the workplace of the first two factors mentioned above.¹¹⁰ It is the quantity of light, both direct and

¹⁰⁸Walter Sturrock, "Levels of Illumination," Special Bulletin, Lamp Department, General Electric Company, Cleveland.

¹⁰⁹Recommended Practice of Industrial Lighting, Illuminating Engineering Society, New York.

¹¹⁰The net effect of these two factors in terms of foot-candles may be determined with sufficient accuracy by means of a photo-electric exposure meter such as used by amateur photographers. For this purpose it is desirable to use a meter calibrated to indicate foot-candles of incident light directly on the scale. The use of the instrument is so simple that every industrial organization will have a number of people capable of making a general analysis of their current illumination levels. The results may then be checked against a table of recommended values for the specific types of operations. It should be noted in this connection that the tables of recommended values now in use are based on contemporary good practice and not necessarily on optimum values. The tables are revised upwards from time to time in conformity with the growing recognition of the values of good seeing.

reflected, incident upon the workplace (or any other point where a reading may be taken). The process of seeing, however, involves additional factors so that one task may require ten times as many foot-candles to provide the same relative ease of seeing as another. The problem, then, has been to determine some standard seeing task, together with a method for comparing other tasks to it, in order to have a sound basis for prescribing foot-candles of illumination. A considerable amount of basic research on this problem has been done by Luckiesh of the General Electric Lighting Research Laboratory. Using a conservative standard of 10 foot-candles for reading high-quality 8-point type he found¹¹¹ that to use a steel scale (1/64 inch divisions) with equal ease of seeing required about 150 foot-candles. Such values of illumination are rare in industry today. When the plant of Graflex, Inc. at (manufacturers of cameras and photographic instruments) Rochester, New York, was modernized "all local lighting was abolished. . . it was felt that an intensity of 28 foot-candles of general illumination should be sufficient!"¹¹²

¹¹¹Matthew Luckiesh, Light, Vision and Seeing, New York: D. Van Nostrand Co.. Luckiesh selected the threshold visibility of 8-point Bodoni Book Monotype printed with best black ink on excellent white paper as his base point. For his basic degree of visibility he used this base type with 10 foot-candles of illumination. This is a quite conservative level, representing a relatively low degree of seeing ease (approximately, the illumination at three feet from an indirect three-way floor lamp at its lowest level - 100 watts). Determination of the foot-candles required on other tasks to provide the same relative ease of seeing was made by means of the Luckiesh-Moss Visibility Meter developed especially for that purpose.

¹¹²V. G. Rollins, op. cit., p.141

In the recently modernized automatic precision screw-machine department of the Brown Instrument Company, Philadelphia, an intensity of at least 50 foot-candles at machine levels is provided.¹¹³ Not only would these be judged low on the basis of Luckiesh's study, but they are also substantially below the currently recommended 100 foot-candles for Find Bench and Machine Work, Fine Automatic Machines, Medium Grinding, Fine Buffing and Polishing.¹¹⁴

Deficient illumination is frequently found where recommended levels are 50 foot-candles or more (as well as in other cases). A partial explanation may be derived from the fact that the change in foot-candles needed to effect a significant change in the ease of seeing is in the nature of a geometric progression. Thus, a substantial improvement over a level of 50 foot-candles would require about 100 foot-candles. Power, equipment, and wiring costs would be appreciably higher. Faced with this problem, the majority of executives appear to choose what is, on the surface, the less costly alternative. However, even a two percent increase in production, or a decrease in rejects or accidents might far more than offset a one-hundred percent increase in lighting costs. It would be desirable in such cases to make an analysis of the cost of the hazard (inadequate lighting) in terms of spoilage, lowered efficiency, accidents, etc.. If this were done, the

¹¹³G. H. Fry, Jr., "Better Plant Facilities Increase Production," Factory Management & Maintenance, 104:142, March, 1946.

¹¹⁴W. Sturrock, op. cit., p. 11.

result would probably establish the economy of supplying illumination in accordance with recommended standards similar to those presented in abbreviated form in Appendix C, Page 111.

Sources of Illumination. The cheapest form of illumination is, of course, daylight. The use of daylight exclusively, however is limited to single story plants where window area equal to at least 30% of the floor area can be provided. Designing to secure adequate lighting by means of daylight is facilitated by the use of light distribution charts such as those published in the Production Handbook.¹¹⁵ Even so, auxiliary general illumination may be needed at various times and some tasks may require continuous supplemental lighting to secure the required levels of illumination. Factors which have contributed to a decrease in the popularity of daylighting for industrial plants are:

1. Multiple-shift operation. (Full artificial lighting needed for night operation).
2. Loss of light (during night operations) through large glass areas.
3. High heat loss (and gain, in the summer months) through glass areas as compared to walls. Additional cost of heating or cooling may be greater than cost of complete artificial illumination.
4. Constant fluctuation of daylight intensities.
5. Maintenance problems on large glass areas in dirty locations.

The extreme case in the current trend is the exclusive use of artificial illumination in the "windowless" plant, a number of which have been

¹¹⁵L. P. Alford and J. R. Bangs, op. cit., pp.793-800.

constructed in recent years.¹¹⁶

Artificial light sources are of three general types according to the method of producing light. (the incandescent arc-lamp is not included because its applications are not within the field under consideration):

1. Incandescent filament (14 to 22 lumens per watt)
2. Mercury Vapor (25 to 38 lumens per watt)
3. Fluorescent (27 to 58 lumens per watt)

Fluorescent lighting dominates the field in new plant construction and in modernization plans. Although the cheapest fixtures are about twice the cost of basic incandescent fixtures, the savings on wiring and power costs (due to higher efficiency) are off-setting items. Although the lamps themselves are somewhat more expensive in the smaller sizes their life is considerably greater than that of an incandescent lamp. Furthermore, the quality of lighting is much better for general illumination, and the problem of eliminating glare is much simpler with fluorescent lighting. Tests indicate that the automatic compensation made by the human eye to protect itself from glare reduces the effectiveness of the light actually provided by 42% to 84%.¹¹⁷ To secure diffuse and glareless illumination, such as obtained with fluorescent units, by means of incandescent lighting requires more expensive and less efficient

¹¹⁶"Recent New Plants," Factory Management & Maintenance, (Part II, Industrial Plant Buildings) 104:B-55, April, 1946.

¹¹⁷R. E. Simpson, "Illumination and Accident Prevention," paper presented before the Grand Rapids (Michigan) Safety Council, May 6, 1930.

fixtures - thus reducing the apparent first-cost advantage of the method and increasing the operating cost. This is clearly illustrated in Appendix D, Light Load Estimating Chart for various types of incandescent and fluorescent fixtures.

The Mercury Vapor lamp predominates in the field of maximum intensity light sources for high-bay installations. However, a certain amount of incandescent lighting in conjunction with it has been found desirable to modify the unpleasant (to many people) blueish-green quality of mercury vapor light. The incandescent lamp is superior to other types where a concentrated source is required to permit closely controlled distribution. From the standpoint of promoting visibility for the reduction of hazards, the illumination itself is the important factor, and this discussion of light sources is included merely to indicate how it might best be achieved.

There are several factors which should be observed in regard to the lighting equipment and system. All fixtures should be Underwriters Laboratories Approved and should be installed in accordance with the National Electrical Code. A factor often overlooked is the planning of the installation for easy and safe maintenance. The importance of maintenance is indicated by the fact that in industrial plants 20%, on the average, of the potential illumination from installed equipment is lost through an accumulation of dirt on lamps and reflectors.¹¹⁸ Where

¹¹⁸Harris Reinhardt, "Plant Lighting," Factory Management & Maintenance, 105:122, June, 1947.

inaccessible locations cannot be avoided, special fixtures are available which permit lowering the assembly for servicing (the type which automatically breaks the circuit as the fixture is lowered should be specified).

Supplemental Lighting. A general level of illumination sufficient for the most exacting task within a department is usually neither necessary nor economically wise. The solution to the problem is the provision of supplementary lighting at these points to raise the intensity to the recommended level. The intensity ratio of local to general illumination should preferably be not greater than 5 to 1.¹¹⁹ Ratios much greater than this create a hazard similar to that produced by harsh shadows and glare. Visibility is impaired due to excessive contrast and eye fatigue is inevitable.

Much supplemental lighting in the past has been provided by goose-neck or adjustable arm fixtures employing an incandescent bulb in a concentrating reflector. This method is satisfactory for moderate levels but is limited by the relatively high percentage of radiant heat emission by glowing filament lamps. Where high intensities are to be supplied at the workplace without sacrifice of the operator's comfort and efficiency, fluorescent lamps are most desirable. The use of drop or extension lights for supplementary lighting at production machines is an unjustified hazard and implies poor planning of the lighting systems

¹¹⁹Recommended Practice of Industrial Lighting. Illuminating Engineering Society, New York.

An additional use of supplementary lighting which has not been sufficiently stressed in the literature is the concentration of attention on particular hazards such as blind corners, elevator shafts, stairs, changes of floor level, etc.. Warning signs and lights seem to have a type of effectiveness which decreases in proportion to the number of exposures of an individual to the hazard. The motorist who travels a strange route drives more carefully and pays more attention to warning signs as a rule than the selesman who has driven over the route many times. Also, if not carefully engineered a warning may startle or distract attention - thus contributing to, rather than reducing the hazard. Supplementary lighting furnishes an entirely different approach to the problem. Painters, display artists, and others have long known that attention is attracted to a bright area which stands out in contrast to the general background or field of view. Thus, local illumination (which must be at least double the general level to be effective) of the hazard automatically concentrates attention at the point of hazard! Furthermore, the additional illumination provides better visibility at the danger point. These are two of the most important factors in reducing accidents where hazards cannot be completely eliminated. The use of coded safety colors is also desireable and is considered in the following section.

PAINTING

Selection of the proper types and colors of paint for the plant interior and equipment will contribute to the reduction of hazards in

several ways and will also yield other substantial benefits.

1. High-reflectivity paints increase useful illumination - are especially effective in lightening shadows which do not receive direct illumination.
2. Special high-visibility safety colors warn employees of hazards, mark location of first-aid equipment, etc.
3. Proper color selection subdues background detail - concentrates attention on point of operation.
4. Employee fatigue is reduced through use of psychologically effective colors.
5. Good housekeeping is facilitated in an attractive plant.
6. Morale, productivity, etc., are frequently influenced by a painting program.

The psychological effects of color have been recognized by artists for centuries, yet, strangely, it is only in recent times that color has been made an effective tool in advertising and packaging goods for consumer appeal. Much less attention has been devoted to the application of color to the place where the goods are produced. There is, however, no basis for assuming that people, as customers, will be influenced by the adept application of color while people, as employees, will not. As a matter of fact, the major paint manufacturers in recent years have devoted substantial study to industrial applications of color. Special types and colors of paint have been developed and trained service personnel are retained for consultation with industrial consumers. As a result of their efforts and the recognition by progressive management of the long-ignored potentialities of color in industrial plants there is a steady increase in the applications of "color dynamics" or "color conditioning" (trade-names of the Pittsburgh

Plate Glass and DuPont firms, respectively). The paint manufacturers have not overlooked hazard reduction potentialities of color dynamics, but it is encouraging to note that many applications have repaid their cost out of direct increases in worker productivity. This should be an effective persuasion for the inclusion of a complete painting plan as a part of plant layout and design.

Colors for Equipment. Brainerd and Denning¹²⁰ conducted investigations to determine the most effective colors or combinations of colors for machine tools. All other conditions were maintained as constant as possible while time studies were made. Under both incandescent and mercury light sources they found a combination of medium gray for the frame and structural parts with buff for the working area or point-of-operation to be the most effective. Aluminum finish overall was the least effective, the job studied requiring 50% more time than when the machine was finished with the optimum color combination. The test results indicated that with all other conditions constant the same job required about 18% longer to perform under the mercury vapor light source than it did under the incandescent. Here, the variable was presumed to be the color quality of the light. Unfortunately, these investigators did not conduct the same test with machines painted a uniform dark color as is so frequently found in industrial shops; but their selection of the optimum combination does check with other studies

¹²⁰A. A. Brainerd and M. Denning, "Improved Vision in Machine Tool Operations by Color Contrast," Illumination Engineering, 36:1397-1409, December, 1941.

which found it much more effective than a uniform dark color. The effectiveness of certain color combinations for the painting of equipment is attributed mainly to two factors:

1. Improvement of seeing within the work area due to increased reflected light on the work.
2. Reduction of distracting influences outside the work area, and consequently a reduction in fatiguing eye movement.

Special Paints for Interiors. According to investigations by Brainerd and Massey,¹²¹ useful illumination may be increased over 100% in some cases by re-painting the plant interior with high-reflectivity paints of the proper colors. It should not be expected that such a program could be amortized out of a 50% reduction in illumination power expenses, however, because where such conditions are encountered the general level of illumination is nearly always much too low. In some plants it would be found that, even after such a modernization of the interior structural surfaces, the general level of lighting would be below the recommended values. In the average plant where the interior has received some previous attention the improvement would more likely be of the amount reported for the Gillette Safety Razor Company plant at Boston where from 5 to 10% increases due to higher reflectivity were noted.¹²²

¹²¹A. A. Brainerd and R. A. Massey, "Salvaging Waste Light For Victory," Illuminating Engineering, 37:738-751, December, 1942.

¹²²W. J. L. Roop, "Painted the Plant in Colors - Here's How," Factory Management & Maintenance, 105:91-93, June, 1947.

Safety Color Codes. There is nothing particularly new about color codes; in industry they have been used for some time for identifying electrical circuits, piping and alloy steel stock. It was not until World War II, however, that the idea of a safety color code was fully developed. In 1944 the DuPont Finishes Division proposed a code consisting of six colors. In 1945 the American Standards Association safety color code was established as a war safety measure. The A.S.A. code prescribes four standard colors, using red for three warnings - danger, stop, and fire. Since fire, of hazards, is most likely to result in panic and confusion it is felt that there is some merit in the DuPont position that red should be reserved for fire equipment and safety devices only. However, too many code colors can also be a source of confusion. Further, the color ("alert orange") proposed as a substitute for red to indicate danger might easily be confused with red by a person in a state of excitement. Under the circumstances, therefore, it has yet to be proved that colors in addition to those prescribed by the A.S.A. code actually are justified.

The safety color code is not a substitute for the elimination or guarding of hazards - it is a supplementary device. Furthermore, the effectiveness of the method can be totally defeated by indiscriminate application. Most industrial paint manufacturers furnish manuals and an advisory service to insure best results in the use of the color code.

It is difficult to evaluate the effectiveness of the safety color code in reducing accidents. Substantiated records show reductions of from 50 to 90% in accident frequency rates following employment of

the code, and the paint manufacturers imply that this is a measure of its effectiveness. In many cases, however, the safety color code was but a single part of an intensive accident prevention program and so its share in the results cannot be isolated. Other cases were new war-production plants where initial statistics reflected conditions of inexperienced personnel and primary emphasis on getting the plant into production. Later figures show the results of training and experience of personnel and efforts to improve efficiency, as well as specific attention to the control of hazards. Still, the safety color code is of sufficient value to be adopted in every plant. Its application will frequently call attention to hazards that can be eliminated or more adequately guarded. Also, the very process of instituting the system will awaken employee interest and, if followed up by management in other ways, will pay dividends in addition to a reduction in accident rates.

Psychological Effects. Some judgement is required in the use of a table or selector for determining color schemes for industrial interiors. A purely mechanistic approach to the problem will almost certainly fail to yield the full possibilities of "color conditioning." Color itself can be monotonous unless the color patterns are intelligently varied throughout the plant. Cafeterias, locker and recreation rooms, corridors, and similar areas are best planned to contrast with the production areas. Only moderate contrasts are advisable between various production areas.

No quantitative measurements can easily be made of the psychological effects of modernizing a plant interior through painting - or of other improvements in working conditions. At the same time, the vast majority of organizations which have made such changes are well-pleased with the results. Sometimes a reduction in hazards is immediate and quite apparent, in other cases the relationship is questionable; but in nearly all cases the total net result of improved employee facilities has been beneficial to all concerned. Mention has been made of the Gillette Safety Razor Company; their Chief Engineer writes:

"A paint-up program costs a good deal of money. But it pays. It has paid us because the new paint has done things to worker morale. It has made the plant a pleasanter place to work. It has provided an urge to keep the plant clean. And, not to be overlooked, it has improved overall illumination."¹²³

¹²³W. J. L. Roop, op. cit., p.90.

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- "The Floor Underfoot," National Safety News, 55:89, March, 1946.

"Trends in Plant Design and Construction," (1947), Factory Management & Maintenance, (Part II, Industrial Plant Buildings), 105:B 44-45, April, 1947.

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"What Better Lighting Did For One Shop," National Safety News, 53:78, March, 1946.

Wheeler, W. S., "Economical Handling In A Warehouse," Factory Management & Maintenance, 105:127, June, 1947.

C. SAFETY BULLETINS AND PAMPHLETS

(listed according to issuing agency)

American Standards Association, 29 West 39th Street, New York. (List of "American Standard" Safety Codes on request.)

National Board of Fire Underwriters, 85 Johns Street, New York 7.
(List of NBFU Standards, Regulations, and Suggestions in pamphlet form on request.) The following have been referred to in the text and are partially indicative of the entire list:

<u>Title</u>	<u>Pamphlet No.</u>
Blower and Exhaust Systems	91
Combustible Fibres	44
National Electrical Code	70
Paint Spraying and Spray Booths	33
Protection of Openings in Walls, etc.	80
Pyroxylin Plastic	42
Waterproofing of Floors, and Drainage	92

National Conservation Bureau, 60 John Street, New York. Handbook of Industrial Safety Standards. 190 pp.

National Fire Protection Association, 60 Batterymarch Street, Boston. Handbook of Fire Prevention (Crosby - Fiske - Forster), Ninth Edition, 1941, 1307 pp.. (Tenth Edition, 1947)

National Safety Council, 20 North Wacker Drive, Chicago. (List of publications on request). The following selected titles are of general interest. All are from the General Safe Practices series except those marked with an asterisk*, which are from the Health Practices series.

<u>Title</u>	<u>Pamphlet No.</u>
Electric Equipment	29
Exhaust Systems	32
Falls of Workers - Causes & Prevention	99
Fire Causes & Prevention	31
Fire Extinguishment	24
Floors & Flooring	11
Identification of Piping Systems	88
Industrial Dust	4
Industrial Power Departments	96
Industrial Sanitation	27
Industrial Shop Lighting	22
Industrial Ventilation	37
Lighting and Health	18
Machine Shops	39
Mechanical Power Transmission Equip.	7,8,9,10
Stairs & Ramps	2

D. MISCELLANEOUS BULLETINS

Air Conditioning and the Comfort of Workers, (Industrial Health Series - No. 5), Metropolitan Life Insurance Company, New York. 20 pp.

Effect of Noise on Hearing of Industrial Workers, Special Bulletin 166, New York Department of Labor. New York: 1930.

Lunchrooms for Employees. A Report of the Policyholders Service Bureau, Metropolitan Life Insurance Company, New York: n.d. 28 pp.

Recommended Practice of Industrial Lighting, Illuminating Engineering Society, New York.

Simpson, R. E., "Illumination and Accident Prevention," paper presented before the Grand Rapids (Michigan) Safety Council, May 6, 1930.

Sturrock, Walter, "Levels of Illumination," Special Bulletin, Lamp Department, General Electric Company, Cleveland.

Texas City, Texas, Disaster. Report by Fire Prevention and Engineering Bureau of Texas (Dallas, Texas) and The National Board of Fire Underwriters, New York. 44 pp.

APPENDICES

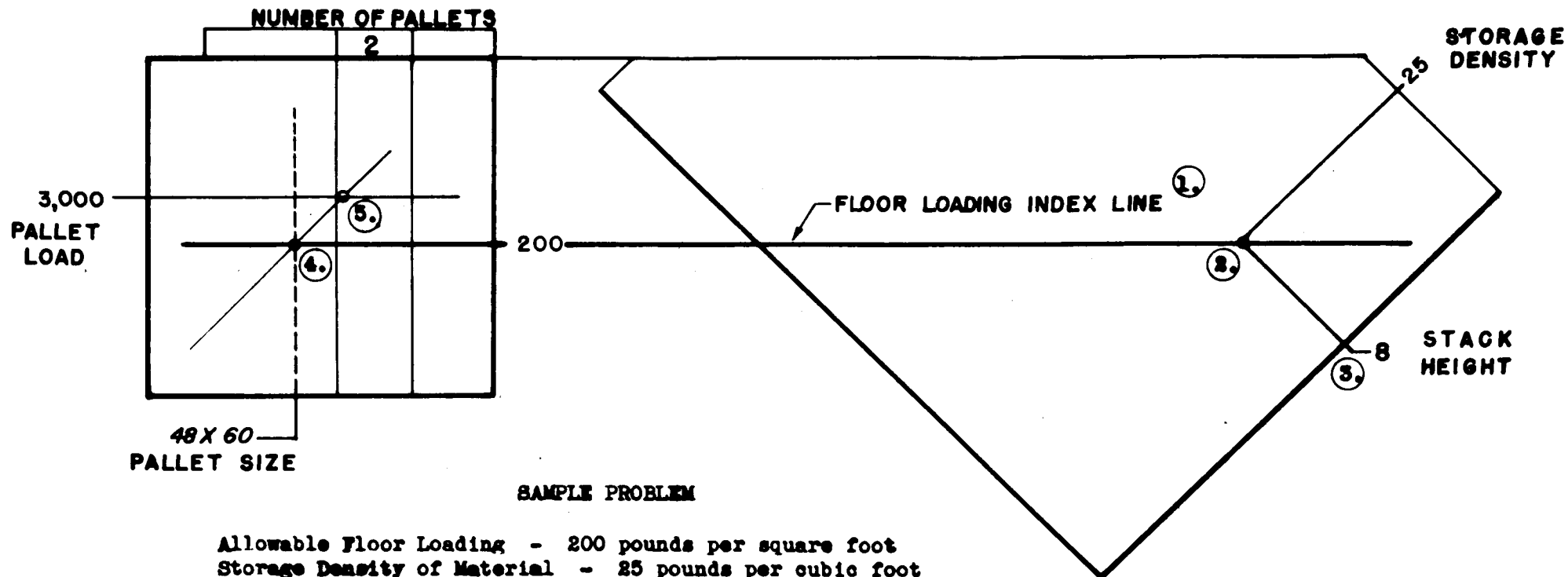
APPENDIX A.

CALCULATING CHART FOR PALLETIZED STORAGE

Explanatory Note: The calculating chart (page 106) is constructed about a series of horizontal lines representing allowable floor loading in the storage area. The two grids related by the index lines are merely a device for adding and subtracting logarithms graphically. Where the calculator is to be used for an area having the same floor loading limit throughout, the corresponding index line may be drawn in extra-heavy with ink to facilitate use of the chart. The following directions, however, apply for any situation.

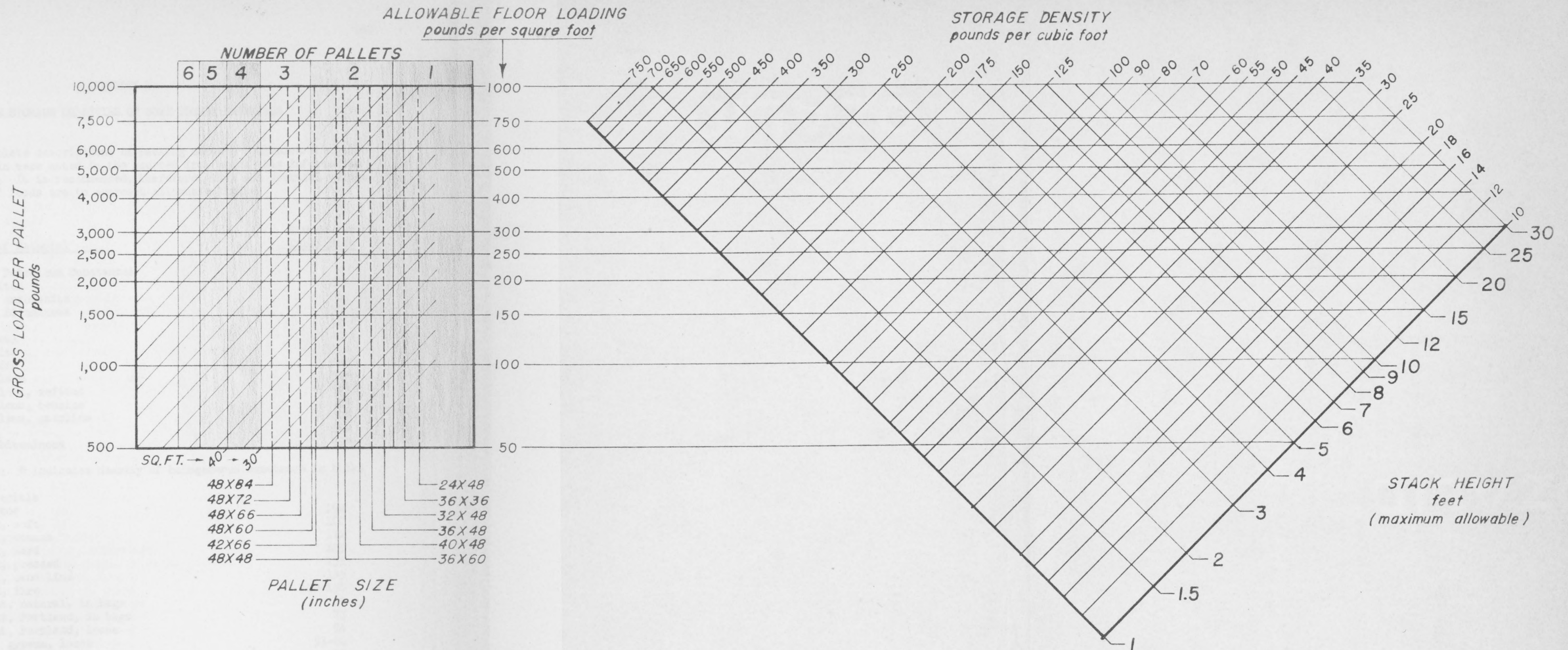
1. Locate the horizontal index line corresponding to the maximum allowable floor loading for the storage area. (If this limit is not known it should be determined by a competent structural engineer on present state-of-structure basis with an adequate safety factor.)
 2. Determine storage density of material from tables, records, or shipping data and locate this value on the scale. Follow storage density line downward to left where it intersects index line.
 3. From point of intersection determined in step 2 trace line sloping down to right. Scale indicates maximum stacking height for that particular material.
 4. Follow index line to left to intersection with dotted line which represents the size of pallet to be used. *
 5. From point located in step 4 follow sloping line up or down to horizontal line corresponding to gross pallet load (scale at left of grid). The zone in which this intersection point falls determines the required number of pallets per stack in accordance with the scale at top of grid.
- * Where a special size pallet not listed on the calculator is to be used a line may be added by interpolation on the basis of area between pallet sizes already plotted.

USE OF RAPID CALCULATOR FOR PALLETIZED STORAGE



Allowable Floor Loading - 200 pounds per square foot
 Storage Density of Material - 25 pounds per cubic foot
 Size of Pallet to be used - 48 x 60 inches
 Maximum Gross Pallet Load - 3,000 pounds

- ① Location of Floor Loading Index Line
- ② Location of point of intersection - storage density and index lines
- ③ Maximum stack height - 8 feet
- ④ Location of pallet size point (intersection of pallet size and index lines)
- ⑤ Intersection of sloping line through point 4. with pallet load line; determination of number of pallets - 2 pallets



RAPID CALCULATOR FOR PALLETIZED STORAGE

APPENDIX B

AVERAGE STORAGE DENSITIES OF SOME COMMON MATERIALS

Note: Incomplete descriptions of packing methods for which the given values pertain were noted in the sources from which this information was obtained. It is recommended, therefore, that all doubtful values be checked if loads are to approach allowable limits

<u>Type of Material</u>	<u>Pounds per Cubic Foot</u>
Bituminous & Petroleum Substances	
Asphaltum	81*
Coal, Anthracite	66
Coal, Bituminous	55
Coke	32
Charcoal	20
Graphite	131*
Paraffin	56*
Petroleum	54*
Petroleum, refined	50*
Petroleum, benzine	46*
Petroleum, gasoline	42*
Pitch	69*
Tar, bituminous	75*

(Note: * indicates density of homogeneous substance in bulk)

Building Materials	
Asbestos	192
Brick, soft	100
Brick, common	112
Brick, hard	125
Brick, pressed	135
Brick, sand lime	135
Brick, fire	140-150
Cement, natural, in bags	59
Cement, Portland, in bags	73
Cement, Portland, loose	94
Lime, gypsum, loose	53-64
Lime and plaster, in bags	53
Plaster of Paris	93-113
Sand, gravel, dry, loose	90-105
Sand, gravel, dry, packed	100-120
Stone, crushed	100
Tile	110-120

Appendix B (continued)

<u>Type of Material</u>	<u>Pounds per Cubic Foot</u>
Cereals and Grains	
Barley	39
Bran	16
Corn, shelled	45
Corn, in ear	56
Oats	26
Rye	45
Wheat	48
Drugs, Paints, Oil, etc.	
Alum, pearl, in barrels	33
Beaching powder, in hogsheads	31
Blue vitriol, in barrels	45
Glycerin, in cases	52
Linseed oil, in barrels	36
Linseed oil, in drums	45
Red lead, and litharge, dry	132
Rosin, in barrels	48
Shellac, gum	38
Soda ash, in hogshead	62
Soda, caustic, in drums	88
Sulphuric acid, in carboys	60
Soda, silicate, in barrels	53
White lead paste, in cans	174
White lead, dry	86
Dry Goods, Fibres, etc.	
Burlap, in bales	43
Coir Yarn, in bales	33
Cotton, in bales, compressed	18
Cotton, bleached goods, in cases	28
Cotton flannel, in cases	12
Cotton sheeting, in cases	23
Cotton yard goods, in cases	25
Excelsior, compressed	19
Hemp, Italian, compressed	22
Hemp, Manila, compressed	30
Jute, compressed	41
Linen damask, in cases	50
Linen goods, in cases	30-40
Sisal, compressed	21
Tow, compressed	29
Wool, in bales, compressed	48

Appendix B (continued)

<u>Type of Material</u>	<u>Pounds per Cubic Foot</u>
Dry Goods, Fibres, etc.	
Wool, in bales, not compressed	13
Wool, worsted, in cases	27
Groceries, Wines, etc.	
Beans, in bags	40
Canned goods, in cases	58
Coffee, roasted, in bags	33
Coffee, green, in bags	39
Dates, in cases	55
Figs, in cases	74
Flour, in barrels	40
Molasses, in barrels	48
Potatoes, in bags	48
Rice, in bags	58
Sal Soda, in barrels	46
Salt, in bags	70
Soap powder, in cases	38
Starch, in barrels	25
Sugar, in barrels	43
Sugar, in cases	51
Tea, in chests	25
Wines and Liquors, in barrels	38
Hardware, etc.	
Door checks	45
Hinges	64
Locks, in cases, packed	31
Sash Fasteners	48
Screws	101
Wire, insulated, copper, in coils	63
Wire, galv. iron, in coils	74
Wire, magnet, on spools	75
Metals and Alloys	
Aluminum	167
Brass	523
Bronze	552
Copper	556
Iron, gray cast	442
Iron, wrought	485
Lead	710

Appendix B (continued)

<u>Type of Material</u>	<u>Pounds per Cubic Foot</u>
Metals and Alloys	
Nickel	549
Steel	490
Tin	459
Zinc	440
Miscellaneous	
Glass and Chinaware, in crates	40
Hides and leather, in bales	20-40
Paper, newspaper and strawboard	35
Paper, writing and calendered	60
Rope, in coils	32
Rubber Goods	94
Straw and Hay, in bales	20
Timber, Air-dried	
Cedar	22
Fir; Spruce, White Pine; Poplar; Redwood; Cypress	25-28
Pine, red, Oregon, Norway	30-34
Maple, white; Ash; Elm	33-35
Walnut, black	37
Oak; Mahogany; Hickory; Locust; Maple, sugar	42-50
Live Oak	54
Teak	62

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Stocker, H. E., Materials Handling. New York: Prentice-Hall, Inc., 1945 pp. 240-245.

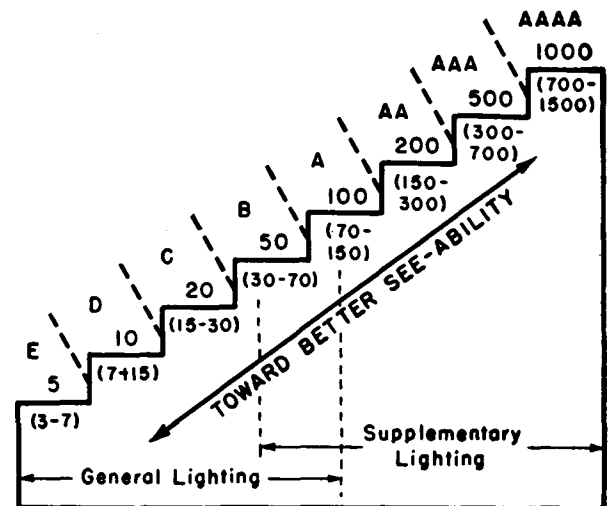
RECOMMENDED LEVELS OF ILLUMINATION

111

Seeing tasks are varied, ranging from casual observation to severe, prolonged, and acute perception of fine details.

When all seeing tasks are graded according to severeness, and footcandle requirements determined for each grade, based upon the fundamental principles of eyesight conservation and seeing comfort, a diagram may be constructed as shown at right. Some variation in seeing severity occurs even within a grade, so the single values appearing in the tables represent modern practice while the range of values given permit slightly lower or higher levels.

Factors other than visual requirements also influence footcandle recommendations—availability of equipment, cost considerations, radiant energy production from light sources, installation requirements, and lighting color—All these factors must be considered in establishing practical recommended levels for the various seeing grades.



Approximately Equal Steps in Footcandle Effectiveness

LEVELS OF SEEING TASKS AND FOOTCANDLES RECOMMENDED

LEVEL A—100 FOOTCANDLES

For very exacting and prolonged seeing tasks, such as fine bench and machine work, extra fine hand painting and finishing, and for the discrimination of fine detail of low contrast. For showcases, wall cases and open counter displays in stores where importance of detail and attention value are prime factors. (Under varying circumstances the footcandles may range from 30% below to 40% above the value given).

LEVEL B—50 FOOTCANDLES

For severe and extensive seeing tasks, such as medium bench and machine work, medium fine assembly and inspection, fine sanding and finishing woodwork, drafting and proofreading. For general merchandising areas in stores, and for show windows in small towns. (Range minus 30% to plus 40%).

LEVEL C—20 FOOTCANDLES

For moderately critical and lengthy seeing tasks, such as rough bench and machine work, medium assembly and inspection, hand painting and finishing, for pressing light cloth products and weaving light woolens. For circulation areas in stores. (Range—minus 30% to plus 40%).

LEVEL D—10 FOOTCANDLES

For visually controlled work in which seeing is important, but more or less interrupted or casual, and does not involve discrimination of fine details or low contrasts. For rough manufacturing processes, such as molding clay products and cements, glass blowing ma-

chines, billet, blooming and sheet bar mills in steel manufacturing. For stock rooms and active storage areas for a variety of small articles such as for merchandise stocks.

LEVEL E—5 FOOTCANDLES

For interiors where crude manual tasks are intermittently carried on, such as required for grinding clay products and cements, stone crushing, hand furnaces and boiling tanks in chemical plants, stock rooms and active storage areas for medium sized materials; for the safe assembly or movement of people in auditoriums, through corridors and stairways. For active work areas out-of-doors—loading docks.

LEVEL AA—200 FOOTCANDLES

For extra fine inspection such as required in making jewelry and precision instruments. For featured items and merchandise displays in show windows in secondary business areas of large cities. (Range minus 30% to plus 40%).

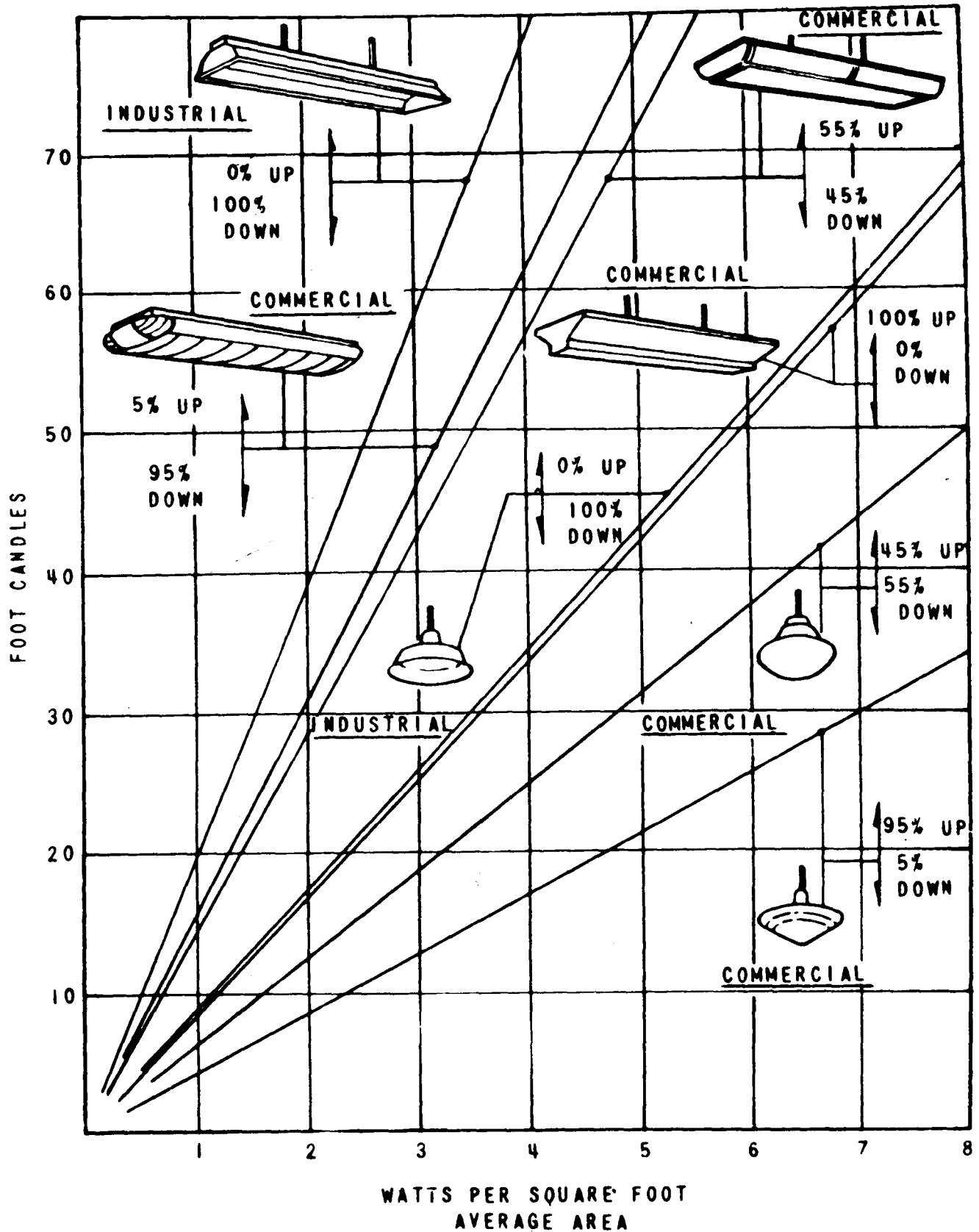
LEVEL AAA—500 FOOTCANDLES

For feature merchandise displays in show windows in main business areas of large cities. For color identification in industry. (Range—minus 30% to plus 40%).

LEVEL AAAA—1000 FOOTCANDLES

Outdoor levels of illumination. For photography, hospital operating rooms and the daytime illumination of show windows. (Range—minus 30% to plus 40%).

LIGHTING LOAD ESTIMATING CHART



Credit: Westinghouse Elec. and Mfg. Co